From the 2018 Administration

AP CollegeBoard

AP Physics C: Mechanics

Practice Exam

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Note: This publication shows the page numbers that appeared in the ***2017–18 AP Exam Instructions*** book and in the actual exam. This publication was not repaginated to begin with page 1.

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Exam Instructions

The following contains instructions taken from the ***2017–18 AP Exam Instructions*** book.

AP Physics C: Mechanics Exam

Regularly Scheduled Exam Date: Monday afternoon, May 14, 2018

Late-Testing Exam Date: Wednesday afternoon, May 23, 2018

Section I	**Total Time:** 45 minutes Calculator Allowed **Number of Questions:** 35 *(The number of questions may vary slightly depending on the form of the exam.)* **Percent of Total Score:** 50% **Writing Instrument:** Pencil required
Section II	**Total Time:** 45 minutes Calculator Allowed **Number of Questions:** 3 **Percent of Total Score:** 50% **Writing Instrument:** Pen with black or dark blue ink, or pencil

Before Distributing Exams: Check that the title on all exam covers is ***Physics C: Mechanics***. If there are any exam booklets with a different title, contact the AP coordinator immediately.

What Proctors Need to Bring to This Exam

- ☐ Exam packets
- ☐ Answer sheets
- ☐ AP Student Packs
- ☐ *2017-18 AP Coordinator's Manual*
- ☐ This book—*2017-18 AP Exam Instructions*
- ☐ AP Exam Seating Chart template
- ☐ School Code and Homeschool/Self-Study Codes
- ☐ Extra calculators
- ☐ Extra rulers or straightedges
- ☐ Pencil sharpener
- ☐ Container for students' electronic devices (if needed)
- ☐ Extra No. 2 pencils with erasers
- ☐ Extra pens with black or dark blue ink
- ☐ Extra paper
- ☐ Stapler
- ☐ Watch
- ☐ Signs for the door to the testing room
  - "Exam in Progress"
  - "Cell phones are prohibited during the test administration, including breaks"

Students are permitted to use rulers, straightedges, and four-function, scientific, or graphing calculators for this entire exam (Sections I and II). Before starting the exam administration, make sure each student has an appropriate calculator, and any student with a graphing calculator has a model from the approved list on page 52 of the *2017-18 AP Coordinator's Manual*. See pages 49–52 of the *AP Coordinator's Manual* for more information. If a student does not have an appropriate calculator or has a graphing calculator not on the approved list, you may provide one from your supply. If the student does not want to use the calculator you provide or does not want to use a calculator at all, they must hand copy, date, and sign the release statement on page 51 of the *AP Coordinator's Manual*.

During the administration of Section II, students may have no more than two calculators on their desks. Calculators may not be shared. Calculator memories do not need to be cleared before or after the exam. Students with Hewlett-Packard 48–50 Series and Casio FX-9860 graphing calculators may use cards designed for use with these calculators. Proctors should make sure infrared ports (Hewlett-Packard) are not facing each other. **Since graphing calculators can be used to store data, including text, proctors should monitor that students are using their calculators appropriately. Attempts by students to use the calculator to remove exam questions and/or answers from the room may result in the cancellation of AP Exam scores.**

Tables containing equations commonly used in physics are included in each AP Exam booklet, for use during the entire exam. Students are NOT allowed to bring their own copies of the equation tables to the exam room.

Students may take both Physics C exams, Mechanics only, or Electricity and Magnetism only. The Mechanics exam is administered first, after which students taking both exams are given a break. Then the Electricity and Magnetism exam is administered. Prior to testing day, determine which exams students are taking. Those taking both Physics C exams and those taking Physics C: Mechanics only should report for the 12 noon start time (11 a.m. in Alaska). Those taking Electricity and Magnetism only should report to the testing room after the break (approximately 2 p.m., 1 p.m. in Alaska). If all students are taking Electricity and Magnetism only, you must not begin the exam before 2 p.m.

The two exams are in separate exam packets, and require separate answer sheets. At the beginning of the session, you will distribute **only** the packets and answer sheets for Mechanics. The materials for Electricity and Magnetism will be distributed after the break.

SECTION I: Multiple Choice

› **Do not begin the exam instructions below until you have completed the appropriate General Instructions for your group.**

This exam includes survey questions. The time allowed for the survey questions is in addition to the actual test-taking time.

Make sure that you begin the exam at the designated time. Remember, you must complete a seating chart for this exam. See pages 303–304 for a seating chart template and instructions. See the *2017-18 AP Coordinator's Manual* for exam seating requirements (pages 55–58).

If you are giving the regularly scheduled exam, say:
It is Monday afternoon, May 14, and you will be taking the AP Physics C: Mechanics Exam.

If you are giving the alternate exam for late testing, say:
It is Wednesday afternoon, May 23, and you will be taking the AP Physics C: Mechanics Exam.

Look at your exam packet and confirm that the exam title is "AP Physics C: Mechanics." Raise your hand if your exam packet contains any title other than "AP Physics C: Mechanics," and I will help you.

Once you confirm that all students have the correct exams, say:

In a moment, you will open the exam packet. By opening this packet, you agree to all of the AP Program's policies and procedures outlined in the *2017-18 Bulletin for AP Students and Parents*.

You may now remove the shrinkwrap from your exam packet and take out the Section I booklet, but do not open the booklet or the shrinkwrapped Section II materials. Put the white seals aside. . . .

Carefully remove the AP Exam label found near the top left of your exam booklet cover. Place it on page 1 of your answer sheet on the light blue box near the top right corner that reads "AP Exam Label.". . .

If students accidentally place the exam label in the space for the number label or vice versa, advise them to leave the labels in place. They should not try to remove the label; their exam can still be processed correctly.

Listen carefully to all my instructions. I will give you time to complete each step. Please look up after completing each step. Raise your hand if you have any questions.

Give students enough time to complete each step. Don't move on until all students are ready.

Read the statements on the front cover of the Section I booklet. . . .

Sign your name and write today's date. . . .

Now print your full legal name where indicated. . . .

Turn to the back cover of your exam booklet and read it completely. . . .

Are there any questions? . . .

You will now take the multiple-choice portion of the exam. You should have in front of you the multiple-choice booklet and your answer sheet. You may never discuss the multiple-choice exam content at any time in any form with anyone, including your teacher and other students. If you disclose the multiple-choice exam content through any means, your AP Exam score will be canceled.

Open your answer sheet to page 2. You must complete the answer sheet using a No. 2 pencil only. Mark all of your responses beginning on page 2 of your answer sheet, one response per question. Completely fill in the circles. If you need to erase, do so carefully and completely. No credit will be given for anything written in the exam booklet. Scratch paper is not allowed, but you may use the margins or any blank space in the exam booklet for scratch work. Rulers, straightedges, and calculators may be used for the entire exam. You may place these items on your desk. Are there any questions? . . .

You have 45 minutes for this section. Open your Section I booklet and begin.



Note Start Time _____. Note Stop Time _____.

Check that students are marking their answers in pencil on their answer sheets and that they are not looking at their shrinkwrapped Section II booklets. You should also make sure that Hewlett-Packard calculators' infrared ports are not facing each other and that students are not sharing calculators.

After 35 minutes, say:

There are 10 minutes remaining.

After 10 minutes, say:

Stop working and turn to the last page in your booklet. . . .

You have 2 minutes to answer Questions 101–106. These are survey questions and will not affect your score. You may not go back to work on any of the exam questions. You may now begin.

To help you and your proctors make sure students are not working on the exam questions, the two pages with the survey questions are identified with a large S on the upper corner of each page. Give students 2 minutes to answer the survey questions.

Then say:

Close your booklet and put your answer sheet on your desk, faceup. Make sure you have your AP number label and an AP Exam label on page 1 of your answer sheet. Sit quietly while I collect your answer sheets.

Collect an answer sheet from each student. Check that each answer sheet has an AP number label and an AP Exam label.

After all answer sheets have been collected, say:

Now you must seal your exam booklet using the white seals you set aside earlier. Remove the white seals from the backing and press one on each area of your exam booklet cover marked "PLACE SEAL HERE." Fold each seal over the back cover. When you have finished, place the booklet on your desk, faceup. I will now collect your Section I booklet. . . .

Collect a Section I booklet from each student. Check that each student has signed the front cover of the sealed Section I booklet.

SECTION II: Free Response

When all Section I materials have been collected and accounted for, say:

May I have everyone's attention? Place your Student Pack on your desk. . . .

You may now remove the shrinkwrap from the Section II packet, but do not open the exam booklet until you are told to do so. . . .

Read the bulleted statements on the front cover of the exam booklet. Look up when you have finished. . . .

Now take an AP number label from your Student Pack and place it on the shaded box. If you don't have any AP number labels, write your AP number in the box. Look up when you have finished. . . .

Read the last statement. . . .

Using your pen, print the first, middle, and last initials of your legal name in the boxes and print today's date where indicated. This constitutes your signature and your agreement to the statements on the front cover. . . .

Turn to the back cover and, using your pen, complete Item 1 under "Important Identification Information." Print the first two letters of your last name and the first letter of your first name in the boxes. Look up when you have finished. . . .

In Item 2, print your date of birth in the boxes. . . .

In Item 3, write the school code you printed on the front of your Student Pack in the boxes. . . .

Read Item 4. . . .

Are there any questions? . . .

I need to collect the Student Pack from anyone who will be taking another AP Exam. Keep it, however, if you will be taking the Physics C: Electricity and Magnetism exam this afternoon. If you have no other AP Exams to take, place your Student Pack under your chair now. . . .

Read the information on the back cover of the exam booklet. Do not open the booklet until you are told to do so. Look up when you have finished. . . .

Collect the Student Packs.

Then say:

Are there any questions? . . .

Rulers, straightedges, and calculators may be used for Section II. Be sure these items are on your desk. . . .

You have 45 minutes to complete Section II. You are responsible for pacing yourself and may proceed freely from one question to the next. You must write your answers in the exam booklet using a pen with black or dark blue ink or a No. 2 pencil. If you use a pencil, be sure that your writing is dark enough to be easily read. If you need more paper during the exam, raise your hand. At the top of each extra sheet of paper you use, write only your AP number and the question number you are working on. Do not write your name. Are there any questions? . . .

You may begin.



Note Start Time _____. **Note Stop Time** _____.

You should also make sure that Hewlett-Packard calculators' infrared ports are not facing each other and that students are not sharing calculators.

After 35 minutes, say:

There are 10 minutes remaining.

After 10 minutes, say:

Stop working and close your exam booklet. Place it on your desk, faceup. . . .

If any students used extra paper for a question in the free-response section, have those students staple the extra sheet(s) to the first page corresponding to that question in their exam booklets. Complete an Incident Report after the exam (see page 67 of the *2017-18 AP Coordinator's Manual* for complete details).

Then say:

Remain in your seat, without talking, while the exam materials are collected. . . .

Collect a Section II booklet from each student. Check for the following:

- Exam booklet front cover: The student placed an AP number label on the shaded box and printed their initials and today's date.
- Exam booklet back cover: The student completed the "Important Identification Information" area.

When all exam materials have been collected and accounted for, return to students who are taking Mechanics only any electronic devices you may have collected before the start of the exam.

If you are giving the regularly scheduled exam, say:
You may not discuss or share the free-response exam content with anyone unless it is released on the College Board website in about two days. Your AP Exam score results will be available online in July.

If you are giving the alternate exam for late testing, say:
None of the content in this exam may ever be discussed or shared in any way at any time. Your AP Exam score results will be available online in July.

If any students completed the AP number card at the beginning of this exam and are about to be dismissed say:

Please remember to take your AP number card with you. You will need the information on this card to view your scores and order AP score reporting services online.

If no students are taking Physics C: Electricity and Magnetism, say:

You are now dismissed.

If some students are taking Physics C: Electricity and Magnetism, say:

Those of you taking Mechanics only are now dismissed.

The students taking the Electricity and Magnetism exam now get a 10-minute break. Remember that the Electricity and Magnetism exam cannot begin before 2 p.m., but should start before 3 p.m.

After the students taking Mechanics only have left, say:

If you will also be taking the Physics C: Electricity and Magnetism exam, please listen carefully to these instructions before we take a 10-minute break. Please put all of your calculators under your chair. Your calculators and all items you placed under your chair at the beginning of this exam must stay there, and you are not permitted to open or access them in any way. You are not allowed to consult teachers, other students, notes, or textbooks during the break. You may not make phone calls, send text messages, check email, use a social networking site, or access any electronic or communication device. If you do not follow these rules, your score will be canceled. Are there any questions? . . .

You may begin your break. Testing will resume at _____ .

If you will be administering Physics C: Electricity and Magnetism at 2 p.m., be sure all exam materials are kept secure during the break. When the students return from break, turn to page 231 and begin the exam administration for Physics C: Electricity and Magnetism.

If you have no students taking Physics C: Electricity and Magnetism, return all exam materials to secure storage until they are shipped back to the AP Program. (See page 26 of the *2017-18 AP Coordinator's Manual* for more information about secure storage.)

After-Exam Tasks

Be sure to give the completed seating chart to the AP coordinator. Schools must retain seating charts for at least six months (unless the state or district requires that they be retained for a longer period of time). Schools should not return any seating charts in their exam shipments unless they are required as part of an Incident Report.

NOTE: If you administered exams to students with accommodations, review the *2017-18 AP Coordinator's Manual* and the *2017-18 AP SSD Guidelines* for information about completing the NAR form, and returning these exams.

The exam proctor should complete the following tasks if asked to do so by the AP coordinator. Otherwise, the AP coordinator must complete these tasks:

- Complete an Incident Report for any students who used extra paper for the free-response section. (Incident Report forms are provided in the coordinator packets sent with the exam shipments.) **These forms must be completed with a No. 2 pencil.** It is best to complete a single Incident Report for multiple students per exam subject, per administration (regular or late testing), as long as all required information is provided. Include all exam booklets with extra sheets of paper in an Incident Report return envelope (see page 67 of the *2017-18 AP Coordinator's Manual* for complete details).
- Before storing materials, check the "School Use Only" section on page 1 of the answer sheet and:
  - Fill in the appropriate section number circle in order to access a separate AP Instructional Planning Report (for regularly scheduled exams only) or subject score roster at the class section or teacher level. See "Post-Exam Activities" in the *2017-18 AP Coordinator's Manual.*
  - Check your list of students who are eligible for fee reductions and fill in the appropriate circle on their registration answer sheets.

Student Answer Sheet for the Multiple-Choice Section

Use this section to capture student responses. (Note that the following answer sheet is a sample, and may differ from one used in an actual exam.)

CollegeBoard AP

Answer Sheet 2018

AP Number Label
(from Student Pack)

AP FPO X123456789 X

AP Exam Label
(from Section I Booklet)

COMPLETE THIS AREA AT EVERY EXAM. **USE NO. 2 PENCIL ONLY**

I am aware of and agree to follow the policies and procedures in the *2017-18 Bulletin for AP Students and Parents* to maintain the security of the exam and the validity of my AP score. I understand and accept that my exam score may be canceled if I do not follow these policies and procedures, if I disregard any exam day instructions, or if my exam is administered improperly. I certify that I am the person whose information appears on this answer sheet.

A. SIGNATURE Sign your legal name as it will appear on your college applications. Date

B. LEGAL NAME Omit apostrophes, Jr., II.

Legal Last Name — First 15 Letters | Legal First Name — First 12 Letters | MI

C. YOUR AP NUMBER

D. EXAM DATE Month Day

E. EXAM START TIME AM PM

F. MULTIPLE-CHOICE BOOKLET SERIAL NUMBER S

G. ONLINE PROVIDER CODE

COMPLETE THIS AREA ONLY ONCE.

I. AREA CODE AND PHONE NUMBER

INTERNATIONAL PHONE

J. SCHOOL YOU ATTEND

SCHOOL CODE | School Name | City | State | Country

K. DATE OF BIRTH

Month: Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec | Day | Year

L. SOCIAL SECURITY NUMBER (Optional)

M. COLLEGE TO RECEIVE YOUR AP SCORE REPORT

COLLEGE CODE

Using the college code listed in the AP Student Pack, indicate the **ONE** college that you want to receive your AP score report.

College Name | City | State | Country

N. CURRENT GRADE LEVEL

- Not yet in 9th grade
- 9th
- 10th
- 11th
- 12th
- No longer in high school

O. STUDENT SEARCH SERVICE®

Colleges and scholarship programs may request your information to inform you of educational opportunities and financial aid.

Would you like us to supply your information?

- Yes
- No

If you don't answer and previously chose to participate in this service, we will continue providing your information.

H. AP EXAM I AM TAKING USING THIS ANSWER SHEET Exam Name: | Form: | Form Code:

801356

SCHOOL USE ONLY

Section Number: 1 2 3 4 5 6 7 8 9

Fee Reduction Granted: 1 Option 1 2 Option 2

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COMPLETE THIS AREA AT EACH EXAM (IF APPLICABLE).

P. SURVEY QUESTIONS — Answer the survey questions in the AP Student Pack. Do not put responses to exam questions in this section.

1	A B C D E F G H I	4	A B C D E F G H I	7	A B C D E F G H I
2	A B C D E F G H I	5	A B C D E F G H I	8	A B C D E F G H I
3	A B C D E F G H I	6	A B C D E F G H I	9	A B C D E F G H I

Q. LANGUAGE — Do not complete this section unless instructed to do so.

If this answer sheet is for the French Language and Culture, German Language and Culture, Italian Language and Culture, Spanish Language and Culture, or Spanish Literature and Culture Exam, please answer the following questions. Your responses will not affect your score.

1. Have you lived or studied for one month or more in a country where the language of the exam you are now taking is spoken?

○ Yes ○ No

2. Do you regularly speak or hear the language at home?

○ Yes ○ No

QUESTIONS 1–75

Indicate your answers to the exam questions in this section (pages 2 and 3). Mark only one response per question for Questions 1 through 120. If a question has only four answer options, do not mark option E. Answers written in the multiple-choice booklet will not be scored.

COMPLETE MARK ● EXAMPLES OF INCOMPLETE MARKS 

You must use a No. 2 pencil and marks must be complete. Do not use a mechanical pencil. It is very important that you fill in the entire circle darkly and completely. If you change your response, erase as completely as possible. Incomplete marks or erasures may affect your score.

1	A B C D E	26	A B C D E	51	A B C D E
2	A B C D E	27	A B C D E	52	A B C D E
3	A B C D E	28	A B C D E	53	A B C D E
4	A B C D E	29	A B C D E	54	A B C D E
5	A B C D E	30	A B C D E	55	A B C D E
6	A B C D E	31	A B C D E	56	A B C D E
7	A B C D E	32	A B C D E	57	A B C D E
8	A B C D E	33	A B C D E	58	A B C D E
9	A B C D E	34	A B C D E	59	A B C D E
10	A B C D E	35	A B C D E	60	A B C D E
11	A B C D E	36	A B C D E	61	A B C D E
12	A B C D E	37	A B C D E	62	A B C D E
13	A B C D E	38	A B C D E	63	A B C D E
14	A B C D E	39	A B C D E	64	A B C D E
15	A B C D E	40	A B C D E	65	A B C D E
16	A B C D E	41	A B C D E	66	A B C D E
17	A B C D E	42	A B C D E	67	A B C D E
18	A B C D E	43	A B C D E	68	A B C D E
19	A B C D E	44	A B C D E	69	A B C D E
20	A B C D E	45	A B C D E	70	A B C D E
21	A B C D E	46	A B C D E	71	A B C D E
22	A B C D E	47	A B C D E	72	A B C D E
23	A B C D E	48	A B C D E	73	A B C D E
24	A B C D E	49	A B C D E	74	A B C D E
25	A B C D E	50	A B C D E	75	A B C D E

FOR OFFICIAL USE ONLY

Exam		0 1 2 3 4 5 6 7 8 9
		0 1 2 3 4 5 6 7 8 9
Exam		0 1 2 3 4 5 6 7 8 9
		0 1 2 3 4 5 6 7 8 9

SELECTED MEDIA EXAMS	R	W	O	OTHER EXAMS	R	W	O
PT02				TOTAL			
PT03				Subscore (if applicable)			
PT04				Subscore (if applicable)			

DO NOT WRITE IN THIS AREA

QUESTIONS 76–120

Be sure each mark is dark and completely fills the circle. If a question has only four answer options, do not mark option E.

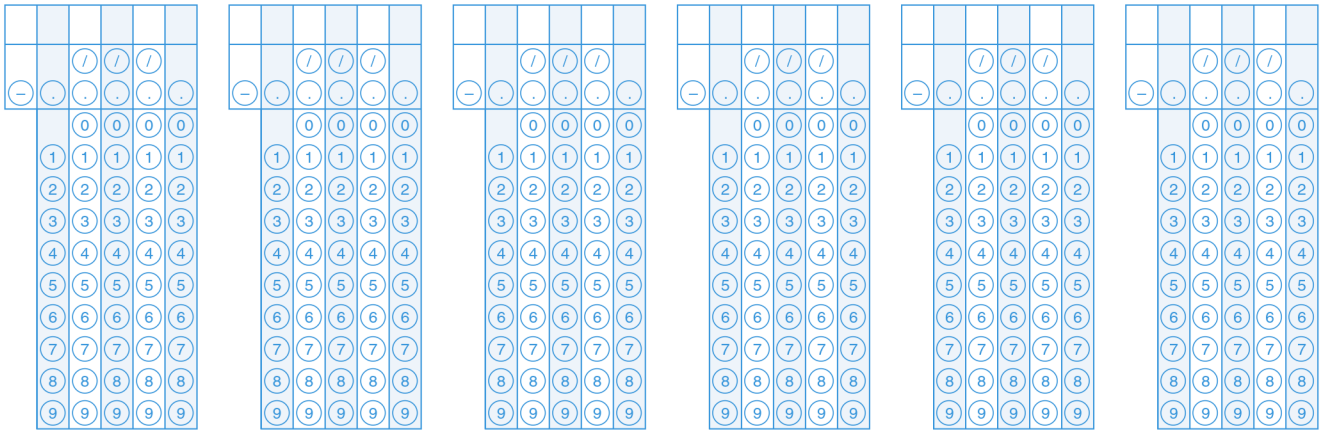
76	A B C D E	91	A B C D E	106	A B C D E
77	A B C D E	92	A B C D E	107	A B C D E
78	A B C D E	93	A B C D E	108	A B C D E
79	A B C D E	94	A B C D E	109	A B C D E
80	A B C D E	95	A B C D E	110	A B C D E
81	A B C D E	96	A B C D E	111	A B C D E
82	A B C D E	97	A B C D E	112	A B C D E
83	A B C D E	98	A B C D E	113	A B C D E
84	A B C D E	99	A B C D E	114	A B C D E
85	A B C D E	100	A B C D E	115	A B C D E
86	A B C D E	101	A B C D E	116	A B C D E
87	A B C D E	102	A B C D E	117	A B C D E
88	A B C D E	103	A B C D E	118	A B C D E
89	A B C D E	104	A B C D E	119	A B C D E
90	A B C D E	105	A B C D E	120	A B C D E

QUESTIONS 121–126

For Students Taking AP Biology

Write your answer in the boxes at the top of the griddable area and fill in the corresponding circles. Mark only one circle in any column. You will receive credit only if the circles are filled in correctly.

121 122 123 124 125 126



QUESTIONS 131–142

For Students Taking AP Computer Science Principles, AP Physics 1, or AP Physics 2

Mark two responses per question. You will receive credit only if both correct responses are selected.

131	A B C D	135	A B C D	139	A B C D
132	A B C D	136	A B C D	140	A B C D
133	A B C D	137	A B C D	141	A B C D
134	A B C D	138	A B C D	142	A B C D

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DO NOT WRITE IN THIS AREA

COMPLETE THIS AREA ONLY ONCE.

R. YOUR MAILING ADDRESS

Use the address abbreviations from your AP Student Pack. Fill in only one circle per column. Indicate a space in your address by leaving a blank box; do not grid that column.

STREET ADDRESS (include street number, street name, apartment number, etc.)

CITY

ZIP OR POSTAL CODE

COUNTRY CODE

STATE

AK HI MI NY VT
AL IA MN OH WA
AR ID MO OK WI
AZ IL MS OR WV
CA IN MT PA WY
CO KS NC RI Puerto Rico
CT KY ND SC
DC LA NE SD AA
DE MA NH TN AE
FL MD NJ TX AP
GA ME NM UT Other
NV VA

V. SEX

- Female
- Male

W. WHICH LANGUAGE DO YOU KNOW BEST?

- English
- English and another language about the same
- Another language

X. RACIAL/ETHNIC GROUP

Please answer both questions about Hispanic origin and about race. For the following questions about your identity, Hispanic origins are not races.

(You may mark all that apply.)

a. Are you of Hispanic, Latino, or Spanish origin?

- No, not of Hispanic, Latino, or Spanish origin
- Yes, Cuban
- Yes, Mexican
- Yes, Puerto Rican
- Yes, another Hispanic, Latino, or Spanish origin

b. What is your race?

- American Indian or Alaska Native
- Asian (including Indian subcontinent and Philippines origin)
- Black or African American (including Africa and Afro-Caribbean origin)
- Native Hawaiian or other Pacific Islander
- White (including Middle Eastern origin)

Y. PARENTAL EDUCATION LEVEL

In the first column, indicate the highest level of education of one parent/guardian, and indicate whether this is your mother/female guardian or father/male guardian. Then, if applicable, indicate the highest level of education of your other parent/guardian in the second column, and indicate whether this is your mother/female guardian or father/male guardian.

- **Mother or female guardian**
- **Father or male guardian**
- Grade school
- Some high school
- High school diploma or equivalent
- Vocational or trade school
- Some college
- Associate or two-year degree
- Bachelor's or four-year degree
- Some graduate or professional school
- Graduate or professional degree

S. FOR STUDENTS OUTSIDE THE UNITED STATES ONLY

If your address does not fit in the spaces provided in Item R, fill in as many circles as you can, then fill in the circle in Item S and print the remainder of your address in the spaces provided.

Address	City	State or Province	Country	ZIP or Postal Code

T. STUDENT IDENTIFIER (Student ID Number)

U. EMAIL ADDRESS

By providing your email address, you are granting the College Board permission to use your email address in accordance with the policies in the *2017-18 Bulletin for AP Students and Parents*.

Section I: Multiple-Choice Questions

This is the multiple-choice section of the 2018 AP Exam.
It includes cover material and other administrative instructions
to help familiarize students with the mechanics of the exam.
(Note that future exams may differ in look from the following content.)

AP® Physics C: Mechanics Exam

SECTION I: Multiple Choice

2018

DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO.

At a Glance

Total Time
45 minutes
Number of Questions
35
Percent of Total Score
50%
Writing Instrument
Pencil required
Electronic Device
Calculator allowed

Instructions

Section I of this exam contains 35 multiple-choice questions. For these questions, fill in only the circles for numbers 1 through 35 on your answer sheet. A table of information and lists of equations that may be helpful are in the booklet. Calculators, rulers and straightedges may be used in this section.

Indicate all of your answers to the multiple-choice questions on the answer sheet. No credit will be given for anything written in this exam booklet, but you may use the booklet for notes or scratch work. After you have decided which of the suggested answers is best, completely fill in the corresponding circle on the answer sheet. Give only one answer to each question. If you change an answer, be sure that the previous mark is erased completely. Here is a sample question and answer.

Sample Question	Sample Answer
Chicago is a (A) state (B) city (C) country (D) continent (E) village	Ⓐ ● Ⓒ Ⓓ Ⓔ

Use your time effectively, working as quickly as you can without losing accuracy. Do not spend too much time on any one question. Go on to other questions and come back to the ones you have not answered if you have time. It is not expected that everyone will know the answers to all of the multiple-choice questions.

Your total score on the multiple-choice section is based only on the number of questions answered correctly. Points are not deducted for incorrect answers or unanswered questions.

Form I
Form Code 4OBP4-S
80

ADVANCED PLACEMENT PHYSICS C TABLE OF INFORMATION

CONSTANTS AND CONVERSION FACTORS

Proton mass,	$m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude,	$e = 1.60 \times 10^{-19}$ C
Neutron mass,	$m_n = 1.67 \times 10^{-27}$ kg	1 electron volt,	1 eV $= 1.60 \times 10^{-19}$ J
Electron mass,	$m_e = 9.11 \times 10^{-31}$ kg	Speed of light,	$c = 3.00 \times 10^{8}$ m/s
Avogadro's number,	$N_0 = 6.02 \times 10^{23}$ mol^{-1}	Universal gravitational constant,	$G = 6.67 \times 10^{-11}$ $\left(\text{N}\cdot\text{m}^2\right)/\text{kg}^2$
Universal gas constant,	$R = 8.31$ J/(mol·K)	Acceleration due to gravity at Earth's surface,	$g = 9.8$ m/s^2
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}$ J/K		

1 unified atomic mass unit,	1 u $= 1.66 \times 10^{-27}$ kg $= 931$ MeV/c^2
Planck's constant,	$h = 6.63 \times 10^{-34}$ J·s $= 4.14 \times 10^{-15}$ eV·s
	$hc = 1.99 \times 10^{-25}$ J·m $= 1.24 \times 10^{3}$ eV·nm
Vacuum permittivity,	$\varepsilon_0 = 8.85 \times 10^{-12}$ C$^2/\left(\text{N}\cdot\text{m}^2\right)$
Coulomb's law constant,	$k = 1/(4\pi\varepsilon_0) = 9.0 \times 10^{9}$ $\left(\text{N}\cdot\text{m}^2\right)/\text{C}^2$
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}$ (T·m)/A
Magnetic constant,	$k' = \mu_0/(4\pi) = 1 \times 10^{-7}$ (T·m)/A
1 atmosphere pressure,	1 atm $= 1.0 \times 10^{5}$ N/m^2 $= 1.0 \times 10^{5}$ Pa

UNIT SYMBOLS	meter,	m	mole,	mol	watt,	W	farad,	F
	kilogram,	kg	hertz,	Hz	coulomb,	C	tesla,	T
	second,	s	newton,	N	volt,	V	degree Celsius,	°C
	ampere,	A	pascal,	Pa	ohm,	Ω	electron volt,	eV
	kelvin,	K	joule,	J	henry,	H		

PREFIXES		
Factor	Prefix	Symbol
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES							
θ	0°	30°	37°	45°	53°	60°	90°
$\sin\theta$	0	1/2	3/5	$\sqrt{2}/2$	4/5	$\sqrt{3}/2$	1
$\cos\theta$	1	$\sqrt{3}/2$	4/5	$\sqrt{2}/2$	3/5	1/2	0
$\tan\theta$	0	$\sqrt{3}/3$	3/4	1	4/3	$\sqrt{3}$	∞

The following assumptions are used in this exam.

I. The frame of reference of any problem is inertial unless otherwise stated.
II. The direction of current is the direction in which positive charges would drift.
III. The electric potential is zero at an infinite distance from an isolated point charge.
IV. All batteries and meters are ideal unless otherwise stated.
V. Edge effects for the electric field of a parallel plate capacitor are negligible unless otherwise stated.

ADVANCED PLACEMENT PHYSICS C EQUATIONS

MECHANICS

$v_x = v_{x0} + a_x t$

$x = x_0 + v_{x0} t + \frac{1}{2} a_x t^2$

$v_x^2 = {v_{x0}}^2 + 2a_x (x - x_0)$

$\vec{a} = \frac{\sum \vec{F}}{m} = \frac{\vec{F}_{net}}{m}$

$\vec{F} = \frac{d\vec{p}}{dt}$

$\vec{J} = \int \vec{F}\, dt = \Delta\vec{p}$

$\vec{p} = m\vec{v}$

$\left|\vec{F}_f\right| \le \mu \left|\vec{F}_N\right|$

$\Delta E = W = \int \vec{F} \bullet d\vec{r}$

$K = \frac{1}{2} m v^2$

$P = \frac{dE}{dt}$

$P = \vec{F} \bullet \vec{v}$

$\Delta U_g = mg\Delta h$

$a_c = \frac{v^2}{r} = \omega^2 r$

$\vec{\tau} = \vec{r} \times \vec{F}$

$\vec{\alpha} = \frac{\sum \vec{\tau}}{I} = \frac{\vec{\tau}_{net}}{I}$

$I = \int r^2 dm = \sum m r^2$

$x_{cm} = \frac{\sum m_i x_i}{\sum m_i}$

$v = r\omega$

$\vec{L} = \vec{r} \times \vec{p} = I\vec{\omega}$

$K = \frac{1}{2} I \omega^2$

$\omega = \omega_0 + \alpha t$

$\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$

a = acceleration
E = energy
F = force
f = frequency
h = height
I = rotational inertia
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
L = angular momentum
m = mass
P = power
p = momentum
r = radius or distance
T = period
t = time
U = potential energy
v = velocity or speed
W = work done on a system
x = position
μ = coefficient of friction
θ = angle
τ = torque
ω = angular speed
α = angular acceleration
ϕ = phase angle

$\vec{F}_s = -k\Delta\vec{x}$

$U_s = \frac{1}{2} k (\Delta x)^2$

$x = x_{\max} \cos(\omega t + \phi)$

$T = \frac{2\pi}{\omega} = \frac{1}{f}$

$T_s = 2\pi\sqrt{\frac{m}{k}}$

$T_p = 2\pi\sqrt{\frac{\ell}{g}}$

$\left|\vec{F}_G\right| = \frac{G m_1 m_2}{r^2}$

$U_G = -\frac{G m_1 m_2}{r}$

ELECTRICITY AND MAGNETISM

$\left|\vec{F}_E\right| = \frac{1}{4\pi\varepsilon_0} \left|\frac{q_1 q_2}{r^2}\right|$

$\vec{E} = \frac{\vec{F}_E}{q}$

$\oint \vec{E} \bullet d\vec{A} = \frac{Q}{\varepsilon_0}$

$E_x = -\frac{dV}{dx}$

$\Delta V = -\int \vec{E} \bullet d\vec{r}$

$V = \frac{1}{4\pi\varepsilon_0} \sum_i \frac{q_i}{r_i}$

$U_E = qV = \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2}{r}$

$\Delta V = \frac{Q}{C}$

$C = \frac{\kappa \varepsilon_0 A}{d}$

$C_p = \sum_i C_i$

$\frac{1}{C_s} = \sum_i \frac{1}{C_i}$

$I = \frac{dQ}{dt}$

$U_C = \frac{1}{2} Q\Delta V = \frac{1}{2} C (\Delta V)^2$

$R = \frac{\rho\ell}{A}$

$\vec{E} = \rho\vec{J}$

$I = Nev_d A$

$I = \frac{\Delta V}{R}$

$R_s = \sum_i R_i$

$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$

$P = I\Delta V$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
ε = emf
F = force
I = current
J = current density
L = inductance
ℓ = length
n = number of loops of wire per unit length
N = number of charge carriers per unit volume
P = power
Q = charge
q = point charge
R = resistance
r = radius or distance
t = time
U = potential or stored energy
V = electric potential
v = velocity or speed
ρ = resistivity
Φ = flux
κ = dielectric constant

$\vec{F}_M = q\vec{v} \times \vec{B}$

$\oint \vec{B} \bullet d\vec{\ell} = \mu_0 I$

$d\vec{B} = \frac{\mu_0}{4\pi} \frac{I\, d\vec{\ell} \times \hat{r}}{r^2}$

$\vec{F} = \int I\, d\vec{\ell} \times \vec{B}$

$B_s = \mu_0 n I$

$\Phi_B = \int \vec{B} \bullet d\vec{A}$

$\varepsilon = \oint \vec{E} \bullet d\vec{\ell} = -\frac{d\Phi_B}{dt}$

$\varepsilon = -L\frac{dI}{dt}$

$U_L = \frac{1}{2} L I^2$

ADVANCED PLACEMENT PHYSICS C EQUATIONS

GEOMETRY AND TRIGONOMETRY

Rectangle

$A = bh$

Triangle

$A = \frac{1}{2}bh$

Circle

$A = \pi r^2$

$C = 2\pi r$

$s = r\theta$

Rectangular Solid

$V = \ell wh$

Cylinder

$V = \pi r^2 \ell$

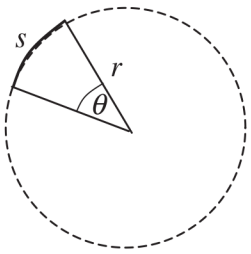
$S = 2\pi r\ell + 2\pi r^2$

Sphere

$V = \frac{4}{3}\pi r^3$

$S = 4\pi r^2$

A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius
s = arc length
θ = angle



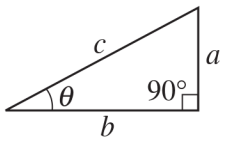
Right Triangle

$a^2 + b^2 = c^2$

$\sin\theta = \frac{a}{c}$

$\cos\theta = \frac{b}{c}$

$\tan\theta = \frac{a}{b}$



CALCULUS

$$\frac{df}{dx} = \frac{df}{du}\frac{du}{dx}$$

$$\frac{d}{dx}\left(x^n\right) = nx^{n-1}$$

$$\frac{d}{dx}\left(e^{ax}\right) = ae^{ax}$$

$$\frac{d}{dx}(\ln ax) = \frac{1}{x}$$

$$\frac{d}{dx}[\sin(ax)] = a\cos(ax)$$

$$\frac{d}{dx}[\cos(ax)] = -a\sin(ax)$$

$$\int x^n\,dx = \frac{1}{n+1}x^{n+1},\ n \neq -1$$

$$\int e^{ax}\,dx = \frac{1}{a}e^{ax}$$

$$\int \frac{dx}{x+a} = \ln|x+a|$$

$$\int \cos(ax)\,dx = \frac{1}{a}\sin(ax)$$

$$\int \sin(ax)\,dx = -\frac{1}{a}\cos(ax)$$

VECTOR PRODUCTS

$\vec{A}\bullet\vec{B} = AB\cos\theta$

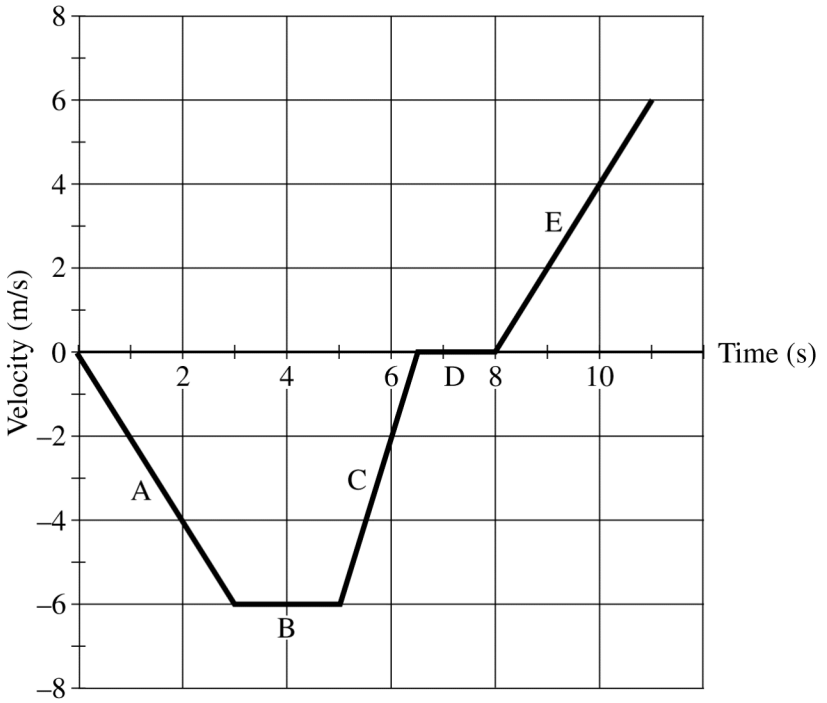
$\left|\vec{A}\times\vec{B}\right| = AB\sin\theta$

PHYSICS C: MECHANICS
SECTION I
Time—45 minutes
35 Questions

Directions: Each of the questions or incomplete statements below is followed by five suggested answers or completions. Select the one that is best in each case and then fill in the corresponding circle on the answer sheet.

Note: To simplify calculations, you may use $g = 10\,\text{m/s}^2$ in all problems.

Questions 1-2



An object is moving along a straight line. The object's velocity as a function of time is shown in the graph above.

1. During which of the labeled segments on the graph is the object moving but not accelerating?

   (A) A
   (B) B
   (C) C
   (D) D
   (E) E

2. The object has a speed of 2 m/s at which of the following times?

   (A) 1 s only
   (B) 6 s only
   (C) 9 s only
   (D) 4 s and 10 s only
   (E) 1 s, 6 s, and 9 s

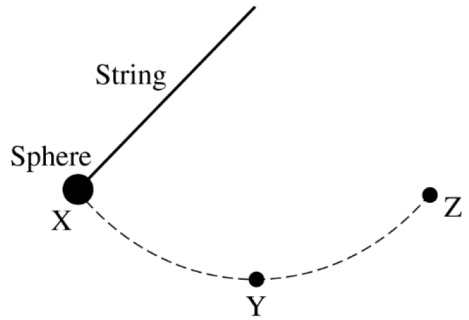
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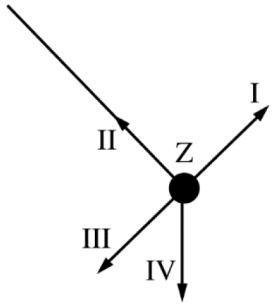
3. An object falls freely from rest under the influence of gravity. If air resistance is negligible, the ratio of the distances traveled during each 1-second time interval by the object during the first, second, and third seconds of its fall is

(A) 1:1:1
(B) 1:2:3
(C) 1:2:4
(D) 1:3:5
(E) 1:4:9

Questions 4-5

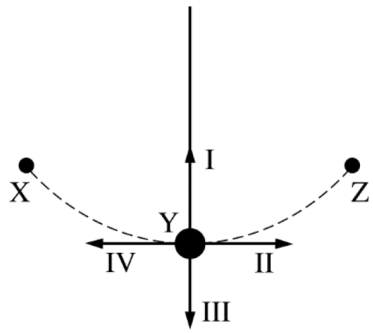


A sphere on the end of a string is released from rest at point X and swings through point Y to point Z, as shown in the figure above. Point Y is the lowest point for the sphere as it swings. Air resistance is negligible.



4. Four directions at point Z are indicated as I, II, III, and IV in the figure above. Which of the arrows best indicates the direction of the acceleration of the sphere at point Z?

(A) I
(B) II
(C) III
(D) IV
(E) The direction of the acceleration is undefined because the acceleration equals zero.



5. Four directions at point Y are indicated as I, II, III, and IV in the figure above. Directions I and III are vertical, II and IV are horizontal, and I is directed along the string. Which of the following best indicates the direction of the acceleration of the sphere at point Y?

(A) I
(B) II
(C) III
(D) IV
(E) The direction of the acceleration is undefined because the acceleration equals zero.

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6. A block of mass m is pulled by a rope along a horizontal surface with negligible friction. For time $t > 0$, the magnitude of the acceleration of the object as a function of time is given by the equation $a = Ae^{-kt}$, where A and k are positive constants. Which of the following expressions determines the impulse exerted on the block by the rope during the time interval $0 < t < t_1$?

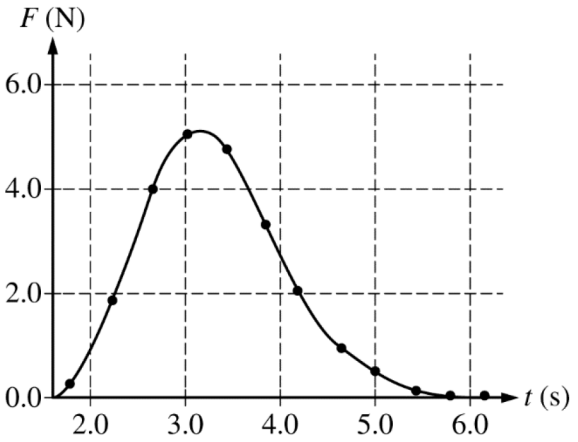
(A) $A\int_0^{t_1} e^{-kt}\,dt$

(B) $mA\dfrac{d}{dt}\left[e^{-kt}\right]_{t_1}$

(C) $A\dfrac{d}{dt}\left[e^{-kt}\right]_{t_1}$

(D) $mAt_1\left[e^{-kt}\right]$

(E) $mA\int_0^{t_1} e^{-kt}\,dt$



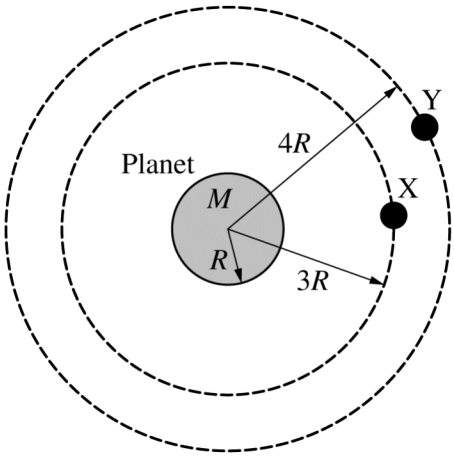
7. A 300 g cart with a force sensor attached starts at rest on a track. The force sensor exerts a force on the cart to speed it up. The graph above shows the force F exerted by the sensor on the cart as a function of time t. The change in the cart's momentum during the time interval shown is most nearly

(A) 4.0 N•s
(B) 8.5 N•s
(C) 13 N•s
(D) 25 N•s
(E) 30 N•s

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GO ON TO THE NEXT PAGE.

Questions 8-10



Identical satellites X and Y of mass m are in circular orbits around a planet of mass M. The radius of the planet is R. Satellite X has an orbital radius of $3R$, and satellite Y has an orbital radius of $4R$. The kinetic energy of satellite X is K_X.

8. In terms of K_X, the gravitational potential energy of the planet-satellite X system is

   (A) $-2K_X$
   (B) $-K_X$
   (C) $-K_X/2$
   (D) $K_X/2$
   (E) $2K_X$

9. The kinetic energy of satellite X is K_X. The kinetic energy of satellite Y is K_Y. The ratio K_X/K_Y is

   (A) 1/4
   (B) 3/4
   (C) 1/1
   (D) 4/3
   (E) 4/1

10. Satellite X is moved to the same orbit as satellite Y by a force doing work on the satellite. In terms of K_X, the work done on satellite X by the force is

    (A) $-K_X/2$
    (B) $-K_X/4$
    (C) 0
    (D) $+K_X/4$
    (E) $+K_X/2$

---

11. Car A can travel around a curved section of road without skidding at a maximum constant speed of 10 m/s. When car B travels around the same curve without skidding at its maximum speed, it has twice the centripetal acceleration as car A. The maximum speed at which car B can safely travel around the curve is most nearly

    (A) 5.0 m/s
    (B) 10 m/s
    (C) 14 m/s
    (D) 20 m/s
    (E) 28 m/s

12. A car is traveling down the highway at speed v when the driver slams on the brakes and skids to a stop in a distance d. Assuming the same frictional force, how far would the car slide if its speed was $2v$?

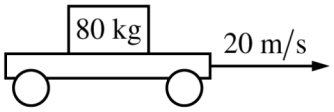
    (A) $d/4$
    (B) $d/2$
    (C) d
    (D) $2d$
    (E) $4d$

13. A 3.0 kg block accelerates at 2.0 m/s^2 because of a constant net force. A block of unknown mass accelerates at 6.0 m/s^2 because of the same net force. What is the mass of the second block?

    (A) 9.0 kg
    (B) 4.0 kg
    (C) 3.0 kg
    (D) 1.5 kg
    (E) 1.0 kg

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14. A cart is moving to the right with a constant speed of $20\ \text{m/s}$. A box of mass 80 kg moves with the cart without slipping. The coefficient of static friction between the box and cart is 0.30, and the coefficient of kinetic friction between the box and cart is 0.15. What are the magnitude and direction of the frictional force acting on the box as it moves with the cart?

(A) Zero
(B) 120 N to the right
(C) 120 N to the left
(D) 240 N to the right
(E) 240 N to the left

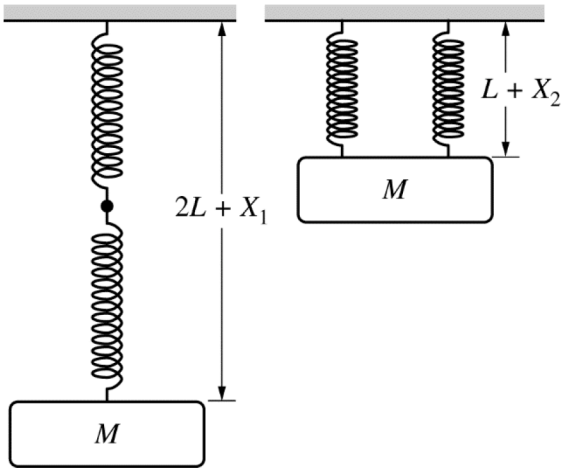


Figure 1 Figure 2

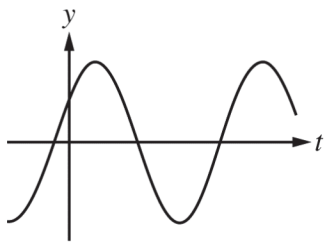
Note: Figure not drawn to scale.

15. A block of mass M is suspended from two identical springs of negligible mass, spring constant $k$and unstretched length L. First, one spring is attached to the end of the other spring. The block is then attached to the end of the second spring and slowly lowered to its equilibrium position. The two springs stretch a total distance of X_1, as shown in Figure 1 above. Next, the springs are hung side by side. The block is attached to the end of the springs and again slowly lowered to its equilibrium position. The springs each stretch a distance of X_2, as shown in Figure 2 above. Which of the following equations correctly shows the relationship between X_1 and X_2?

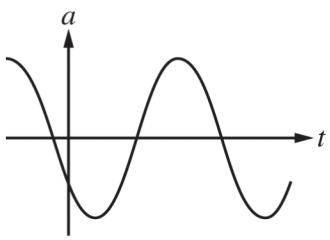
(A) $X_1 = X_2$
(B) $X_1 = \sqrt{2}X_2$
(C) $X_1 = 2X_2$
(D) $X_1 = 4X_2$
(E) $X_1 = 8X_2$

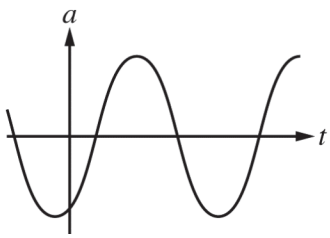
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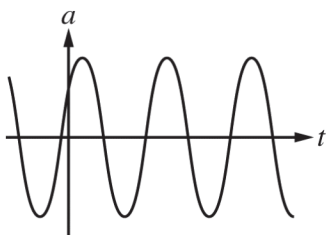
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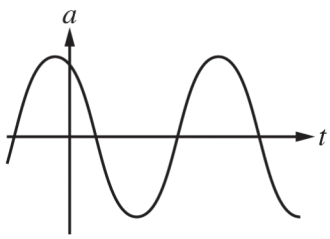


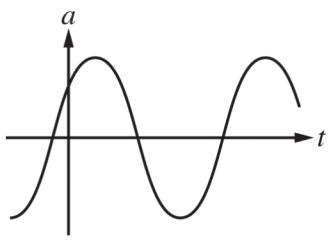
16. A block is hung vertically from an ideal spring. The block is pulled down and allowed to oscillate. The position y as a function for time t is shown in the graph above. Which of the following graphs best represents the acceleration a of the block as a function of time?

(A)


(B)


(C)


(D)


(E)


17. Two moons of equal mass are in circular orbits around a planet. Moon 1 orbits with a radius of r and moon 2 orbits with a radius of $3r$. What is the ratio of the magnitude of the planet's gravitational force on moon 2 to that on moon 1, $F_{G(\text{on } 2)} / F_{G(\text{on } 1)}$?

(A) 9/1
(B) 3/1
(C) 1/1
(D) 1/3
(E) 1/9

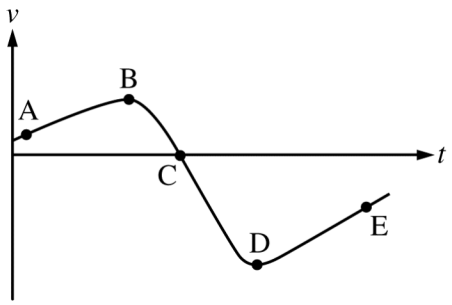
18. A comet moves in an elliptical orbit around the Sun. Which of the following is at a maximum when the comet is at its farthest distance from the Sun?

(A) Kinetic energy of the comet
(B) Speed of the comet
(C) Acceleration of the comet
(D) Gravitational potential energy of the Sun-comet system
(E) Total energy of the Sun-comet system

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Questions 19-20



The graph above shows velocity as a function of time for a cart moving on a straight, horizontal track.

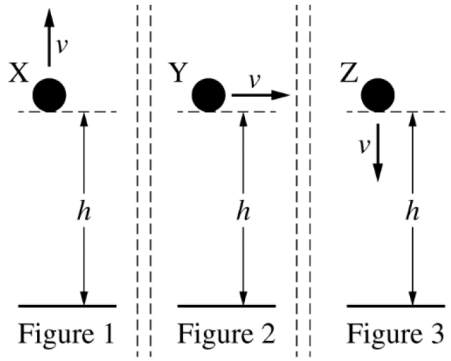
19. At which labeled point does the cart have the greatest speed?

(A) A
(B) B
(C) C
(D) D
(E) E

20. At which labeled point does the velocity of the cart change direction?

(A) A
(B) B
(C) C
(D) D
(E) E

Questions 21-22 are based on the following information.



Three identical spheres are thrown from the same height above the ground. Sphere X is thrown vertically up, sphere Y is thrown horizontally, and sphere Z is thrown vertically down, as shown in figures 1, 2, and 3 above, respectively. All three spheres are thrown with the same speed. Air resistance is negligible.

21. Which sphere or spheres initially collide with the ground with the greatest speed?

(A) Sphere X only
(B) Sphere Y only
(C) Sphere Z only
(D) Spheres X and Z only
(E) All three spheres collide with the same speed.

22. Assume the spheres collide elastically with the ground. Which of the following ranks the spheres based on the rebound height after they collide with the ground?

(A) X > Y > Z
(B) Y > (X = Z)
(C) Z > Y > X
(D) (X = Y) > Z
(E) (X = Z) > Y

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Questions 23-24

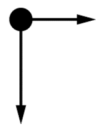
A block on a level horizontal surface of negligible friction is initially traveling at $20\ \text{m/s}$ to the left. A horizontal force $\vec{F}$ is exerted to the right on the block for the time interval $0 < t < 0.10\ \text{s}$. The magnitude of the force is given as a function of time t by the equation $F = \alpha t$, where $\alpha = 240\ \text{N/s}$ and t is in seconds.

23. Which of the following free-body diagrams best shows the forces acting on the block at time $t = 0.05\ \text{s}$?

(A)



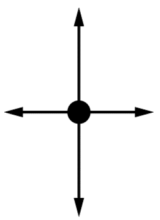
(B)



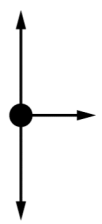
(C)



(D)



(E)



24. What is the magnitude of the change in momentum of the block due to the horizontal force?

(A) $1.2\ \text{kg•m/s}$

(B) $12\ \text{kg•m/s}$

(C) $24\ \text{kg•m/s}$

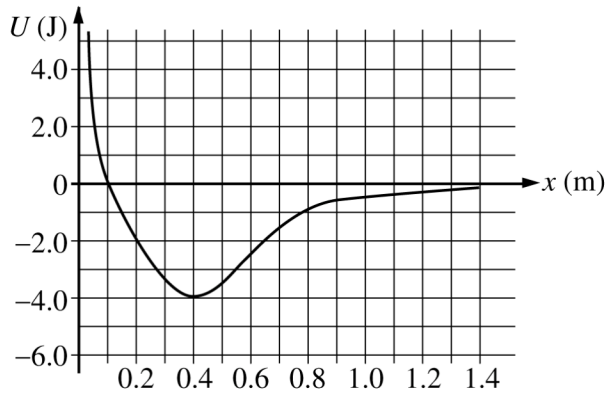
(D) $240\ \text{kg•m/s}$

(E) The change in momentum of the block cannot be determined without knowing the block's mass.

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Questions 25-26



The variable x represents the position of particle A in a two-particle system. Particle B remains at rest. The graph above shows potential energy U of the system as a function of x.

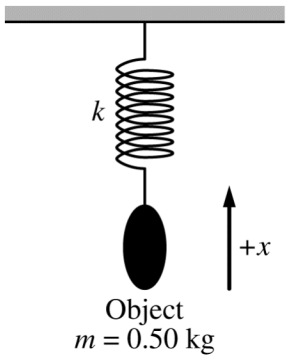
25. If the total energy of the system is -2.0 J, which of the following statements is true?

(A) The system has zero potential energy.
(B) Particle A has 2.0 J of kinetic energy.
(C) The system has 2.0 J of total mechanical energy.
(D) Particle A is always at $x = 0.40$ m.
(E) Particle A oscillates between $x = 0.20$ m and 0.65 m.

26. The x-component of the force on particle A when it is at $x = 0.15$ m is most nearly

(A) –20 N
(B) –2.0 N
(C) –1.0 N
(D) 2.0 N
(E) 20 N

Questions 27-28



A 0.50 kg object is attached to a vertical spring of constant k, as shown above. The object is pulled down and released. The object oscillates vertically. If up is the positive direction, the position x of the object as a function of time t is given by the formula $x = \beta \sin(\omega t + \varphi)$, where $\beta = 0.20$ m, $\omega = 4.0$ rad/s, and $\varphi = \pi/3$ rad.

27. The period of the oscillation for the object is most nearly

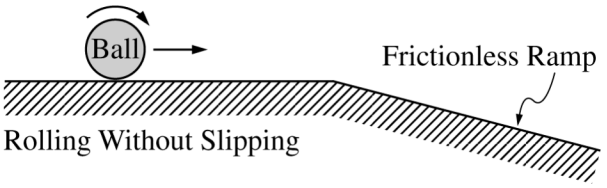
(A) 4.0 s
(B) 3.1 s
(C) 2.0 s
(D) 1.6 s
(E) 1.1 s

28. The magnitude of the maximum acceleration of the object as it oscillates is most nearly

(A) 8.0 m/s^2
(B) 6.4 m/s^2
(C) 3.2 m/s^2
(D) 0.80 m/s^2
(E) 0.013 m/s^2

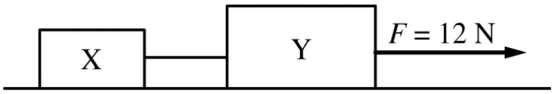
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29. A ball, rolling without slipping on a horizontal surface, encounters a frictionless, downward-sloping ramp, as shown above. Which of the following correctly describes the motion of the ball on the ramp?

(A) Constant translational speed with no angular speed
(B) Increasing translational speed with no angular speed
(C) Increasing translational speed with constant nonzero angular speed
(D) Increasing translational speed with decreasing angular speed
(E) Increasing translational speed with increasing angular speed



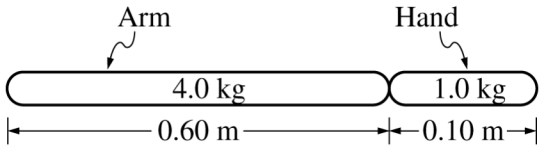
30. Blocks X and Y of masses 3.0 kg and 5.0 kg, respectively, are connected by a light string and are both on a level horizontal surface of negligible friction. A force F = 12 N is exerted on block Y, as shown in the figure above. What is the tension in the string connecting the two blocks?

(A) 1.5 N
(B) 4.0 N
(C) 4.5 N
(D) 7.5 N
(E) 12 N

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Questions 31-32

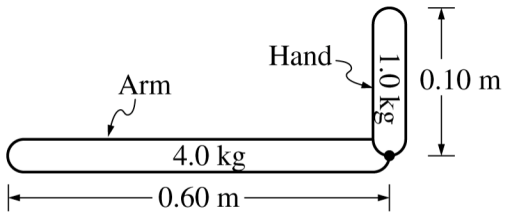


Note: Figure not drawn to scale.

In order to model the motion of an extinct ape, scientists measure its hand and arm bones. From shoulder to wrist, the arm bones are 0.60 m long and their mass is 4.0 kg. From wrist to the tip of the fingers, the hand bones are 0.10 m long and their mass is 1.0 kg. In the model above, each bone is assumed to have a uniform density.

31. When the arm and hand hang straight down, the distance from the shoulder to the center of mass of the arm-hand system is most nearly

(A) 0.25 m
(B) 0.35 m
(C) 0.37 m
(D) 0.50 m
(E) 0.93 m



Note: Figure not drawn to scale.

32. The arm is held in the horizontal position and the hand is bent at the wrist so the fingers point up, as shown in the figure above. The torque exerted by the weight of the hand with respect to the shoulder is most nearly

(A) 6 N•m
(B) 10 N•m
(C) 30 N•m
(D) 60 N•m
(E) 70 N•m

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Questions 33-34

An object moves along a straight line with a velocity v given as a function of time t by the equation $v(t) = \alpha t^2 + \beta t + \gamma$.

33. Which of the following expressions represents $\Delta x(t)$, the displacement of the object as a function of time t starting at time $t = 0$?

(A) 2α

(B) $\alpha t + \beta$

(C) $2\alpha t + \beta$

(D) $\alpha t^3/3 + \beta t^2/2 + \gamma t$

(E) $3\alpha t^3 + 2\beta t^2 + \gamma t$

34. Which of the following expressions represents $a(t)$, the acceleration of the object as a function of time t ?

(A) 2α

(B) $\alpha t + \beta$

(C) $2\alpha t + \beta$

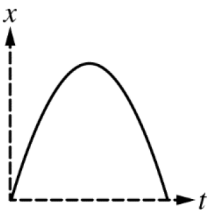
(D) $\alpha t^3/3 + \beta t^2/2 + \gamma t$

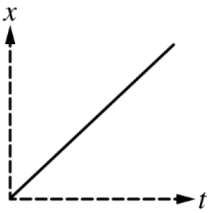
(E) $3\alpha t^3 + 2\beta t^2 + \gamma t$

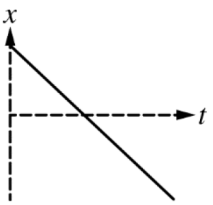
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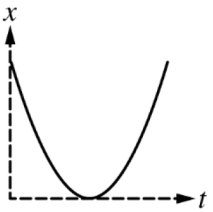
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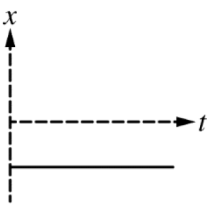
35. A cart is moving in the +x-direction and passes the origin when time t= 0. The cart then moves with decreasing speed, stops, and moves in the –x-direction with increasing speed. Which of the following graphs best represents the cart's position x as a function of time?

(A) 

(B) 

(C) 

(D) 

(E) 

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S T O P

END OF MECHANICS SECTION I

**IF YOU FINISH BEFORE TIME IS CALLED,
YOU MAY CHECK YOUR WORK ON MECHANICS SECTION I ONLY.**

DO NOT TURN TO ANY OTHER TEST MATERIALS.

MAKE SURE YOU HAVE DONE THE FOLLOWING.

- **PLACED YOUR AP NUMBER LABEL ON YOUR ANSWER SHEET**
- **WRITTEN AND GRIDDED YOUR AP NUMBER CORRECTLY ON YOUR ANSWER SHEET**
- **TAKEN THE AP EXAM LABEL FROM THE FRONT OF THIS BOOKLET AND PLACED IT ON YOUR ANSWER SHEET**

Section II: Free-Response Questions

This is the free-response section of the 2018 AP Exam.
It includes cover material and other administrative instructions
to help familiarize students with the mechanics of the exam.
(Note that future exams may differ in look from the following content.)

AP® Physics C: Mechanics Exam

SECTION II: Free Response

2018

DO NOT OPEN THIS BOOKLET UNTIL YOU ARE TOLD TO DO SO.

At a Glance

Total Time
45 minutes
Number of Questions
3
Percent of Total Score
50%
Writing Instrument
Either pencil or pen with black or dark blue ink
Electronic Device
Calculator allowed
Weight
The questions are weighted equally.

IMPORTANT Identification Information

PLEASE PRINT WITH PEN:

1. First two letters of your last name ☐☐
   First letter of your first name ☐
2. Date of birth
   ☐☐ Month ☐☐ Day ☐☐☐☐ Year
3. Six-digit school code
   ☐☐☐☐☐☐
4. Unless I check the box below, I grant the College Board the unlimited right to use, reproduce, and publish my free-response materials, both written and oral, for educational research and instructional purposes. My name and the name of my school will not be used in any way in connection with my free-response materials. I understand that I am free to mark "No" with no effect on my score or its reporting.
   No, I do not grant the College Board these rights. ☐

Instructions

The questions for Section II are printed in this booklet. You may use any blank space in the booklet for scratch work, but you must write your answers in the spaces provided for each answer. A table of information and lists of equations that may be helpful are in the booklet. Calculators, rulers, and straightedges may be used in this section.

All final numerical answers should include appropriate units. Credit for your work depends on demonstrating that you know which physical principles would be appropriate to apply in a particular situation. Therefore, you should show your work for each part in the space provided after that part. If you need more space, be sure to clearly indicate where you continue your work. Credit will be awarded only for work that is clearly designated as the solution to a specific part of a question. Credit also depends on the quality of your solutions and explanations, so you should show your work.

Write clearly and legibly. Cross out any errors you make; erased or crossed-out work will not be scored. You may lose credit for incorrect work that is not crossed out.

Manage your time carefully. You may proceed freely from one question to the next. You may review your responses if you finish before the end of the exam is announced.

Form I
Form Code 4OBP4-S

ADVANCED PLACEMENT PHYSICS C TABLE OF INFORMATION

CONSTANTS AND CONVERSION FACTORS

Proton mass,	$m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude,	$e = 1.60 \times 10^{-19}$ C
Neutron mass,	$m_n = 1.67 \times 10^{-27}$ kg	1 electron volt,	1 eV $= 1.60 \times 10^{-19}$ J
Electron mass,	$m_e = 9.11 \times 10^{-31}$ kg	Speed of light,	$c = 3.00 \times 10^{8}$ m/s
Avogadro's number,	$N_0 = 6.02 \times 10^{23}$ mol^{-1}	Universal gravitational constant,	$G = 6.67 \times 10^{-11}$ $\left(\text{N}\cdot\text{m}^2\right)/\text{kg}^2$
Universal gas constant,	$R = 8.31$ J/(mol·K)	Acceleration due to gravity at Earth's surface,	$g = 9.8$ m/s^2
Boltzmann's constant,	$k_B = 1.38 \times 10^{-23}$ J/K		

1 unified atomic mass unit,	1 u $= 1.66 \times 10^{-27}$ kg $= 931$ MeV/c^2
Planck's constant,	$h = 6.63 \times 10^{-34}$ J·s $= 4.14 \times 10^{-15}$ eV·s
	$hc = 1.99 \times 10^{-25}$ J·m $= 1.24 \times 10^{3}$ eV·nm
Vacuum permittivity,	$\varepsilon_0 = 8.85 \times 10^{-12}$ C$^2/\left(\text{N}\cdot\text{m}^2\right)$
Coulomb's law constant,	$k = 1/(4\pi\varepsilon_0) = 9.0 \times 10^{9}$ $\left(\text{N}\cdot\text{m}^2\right)/\text{C}^2$
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7}$ (T·m)/A
Magnetic constant,	$k' = \mu_0/(4\pi) = 1 \times 10^{-7}$ (T·m)/A
1 atmosphere pressure,	1 atm $= 1.0 \times 10^{5}$ N/m^2 $= 1.0 \times 10^{5}$ Pa

UNIT SYMBOLS	meter,	m	mole,	mol	watt,	W	farad,	F
	kilogram,	kg	hertz,	Hz	coulomb,	C	tesla,	T
	second,	s	newton,	N	volt,	V	degree Celsius,	°C
	ampere,	A	pascal,	Pa	ohm,	Ω	electron volt,	eV
	kelvin,	K	joule,	J	henry,	H		

PREFIXES		
Factor	Prefix	Symbol
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES							
θ	0°	30°	37°	45°	53°	60°	90°
$\sin\theta$	0	1/2	3/5	$\sqrt{2}/2$	4/5	$\sqrt{3}/2$	1
$\cos\theta$	1	$\sqrt{3}/2$	4/5	$\sqrt{2}/2$	3/5	1/2	0
$\tan\theta$	0	$\sqrt{3}/3$	3/4	1	4/3	$\sqrt{3}$	∞

The following assumptions are used in this exam.

I. The frame of reference of any problem is inertial unless otherwise stated.
II. The direction of current is the direction in which positive charges would drift.
III. The electric potential is zero at an infinite distance from an isolated point charge.
IV. All batteries and meters are ideal unless otherwise stated.
V. Edge effects for the electric field of a parallel plate capacitor are negligible unless otherwise stated.

ADVANCED PLACEMENT PHYSICS C EQUATIONS

MECHANICS

$v_x = v_{x0} + a_x t$

$x = x_0 + v_{x0} t + \frac{1}{2} a_x t^2$

$v_x^2 = {v_{x0}}^2 + 2a_x (x - x_0)$

$\vec{a} = \frac{\sum \vec{F}}{m} = \frac{\vec{F}_{net}}{m}$

$\vec{F} = \frac{d\vec{p}}{dt}$

$\vec{J} = \int \vec{F}\, dt = \Delta\vec{p}$

$\vec{p} = m\vec{v}$

$\left|\vec{F}_f\right| \le \mu \left|\vec{F}_N\right|$

$\Delta E = W = \int \vec{F} \bullet d\vec{r}$

$K = \frac{1}{2} m v^2$

$P = \frac{dE}{dt}$

$P = \vec{F} \bullet \vec{v}$

$\Delta U_g = mg\Delta h$

$a_c = \frac{v^2}{r} = \omega^2 r$

$\vec{\tau} = \vec{r} \times \vec{F}$

$\vec{\alpha} = \frac{\sum \vec{\tau}}{I} = \frac{\vec{\tau}_{net}}{I}$

$I = \int r^2 dm = \sum m r^2$

$x_{cm} = \frac{\sum m_i x_i}{\sum m_i}$

$v = r\omega$

$\vec{L} = \vec{r} \times \vec{p} = I\vec{\omega}$

$K = \frac{1}{2} I \omega^2$

$\omega = \omega_0 + \alpha t$

$\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$

a = acceleration
E = energy
F = force
f = frequency
h = height
I = rotational inertia
J = impulse
K = kinetic energy
k = spring constant
ℓ = length
L = angular momentum
m = mass
P = power
p = momentum
r = radius or distance
T = period
t = time
U = potential energy
v = velocity or speed
W = work done on a system
x = position
μ = coefficient of friction
θ = angle
τ = torque
ω = angular speed
α = angular acceleration
ϕ = phase angle

$\vec{F}_s = -k\Delta\vec{x}$

$U_s = \frac{1}{2} k (\Delta x)^2$

$x = x_{\max} \cos(\omega t + \phi)$

$T = \frac{2\pi}{\omega} = \frac{1}{f}$

$T_s = 2\pi\sqrt{\frac{m}{k}}$

$T_p = 2\pi\sqrt{\frac{\ell}{g}}$

$\left|\vec{F}_G\right| = \frac{G m_1 m_2}{r^2}$

$U_G = -\frac{G m_1 m_2}{r}$

ELECTRICITY AND MAGNETISM

$\left|\vec{F}_E\right| = \frac{1}{4\pi\varepsilon_0} \left|\frac{q_1 q_2}{r^2}\right|$

$\vec{E} = \frac{\vec{F}_E}{q}$

$\oint \vec{E} \bullet d\vec{A} = \frac{Q}{\varepsilon_0}$

$E_x = -\frac{dV}{dx}$

$\Delta V = -\int \vec{E} \bullet d\vec{r}$

$V = \frac{1}{4\pi\varepsilon_0} \sum_i \frac{q_i}{r_i}$

$U_E = qV = \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2}{r}$

$\Delta V = \frac{Q}{C}$

$C = \frac{\kappa \varepsilon_0 A}{d}$

$C_p = \sum_i C_i$

$\frac{1}{C_s} = \sum_i \frac{1}{C_i}$

$I = \frac{dQ}{dt}$

$U_C = \frac{1}{2} Q\Delta V = \frac{1}{2} C (\Delta V)^2$

$R = \frac{\rho\ell}{A}$

$\vec{E} = \rho\vec{J}$

$I = Nev_d A$

$I = \frac{\Delta V}{R}$

$R_s = \sum_i R_i$

$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$

$P = I\Delta V$

A = area
B = magnetic field
C = capacitance
d = distance
E = electric field
$\mathcal{E}$ = emf
F = force
I = current
J = current density
L = inductance
ℓ = length
n = number of loops of wire per unit length
N = number of charge carriers per unit volume
P = power
Q = charge
q = point charge
R = resistance
r = radius or distance
t = time
U = potential or stored energy
V = electric potential
v = velocity or speed
ρ = resistivity
Φ = flux
κ = dielectric constant

$\vec{F}_M = q\vec{v} \times \vec{B}$

$\oint \vec{B} \bullet d\vec{\ell} = \mu_0 I$

$d\vec{B} = \frac{\mu_0}{4\pi} \frac{I\, d\vec{\ell} \times \hat{r}}{r^2}$

$\vec{F} = \int I\, d\vec{\ell} \times \vec{B}$

$B_s = \mu_0 n I$

$\Phi_B = \int \vec{B} \bullet d\vec{A}$

$\mathcal{E} = \oint \vec{E} \bullet d\vec{\ell} = -\frac{d\Phi_B}{dt}$

$\mathcal{E} = -L\frac{dI}{dt}$

$U_L = \frac{1}{2} L I^2$

ADVANCED PLACEMENT PHYSICS C EQUATIONS

GEOMETRY AND TRIGONOMETRY

Rectangle

$A = bh$

Triangle

$A = \frac{1}{2}bh$

Circle

$A = \pi r^2$

$C = 2\pi r$

$s = r\theta$

Rectangular Solid

$V = \ell wh$

Cylinder

$V = \pi r^2 \ell$

$S = 2\pi r\ell + 2\pi r^2$

Sphere

$V = \frac{4}{3}\pi r^3$

$S = 4\pi r^2$

Right Triangle

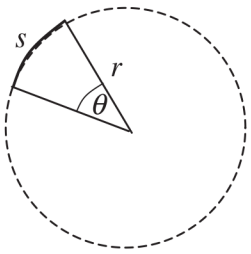
$a^2 + b^2 = c^2$

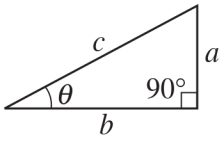
$\sin\theta = \frac{a}{c}$

$\cos\theta = \frac{b}{c}$

$\tan\theta = \frac{a}{b}$

A = area
C = circumference
V = volume
S = surface area
b = base
h = height
ℓ = length
w = width
r = radius
s = arc length
θ = angle





CALCULUS

$$\frac{df}{dx} = \frac{df}{du}\frac{du}{dx}$$

$$\frac{d}{dx}\left(x^n\right) = nx^{n-1}$$

$$\frac{d}{dx}\left(e^{ax}\right) = ae^{ax}$$

$$\frac{d}{dx}(\ln ax) = \frac{1}{x}$$

$$\frac{d}{dx}[\sin(ax)] = a\cos(ax)$$

$$\frac{d}{dx}[\cos(ax)] = -a\sin(ax)$$

$$\int x^n\,dx = \frac{1}{n+1}x^{n+1},\ n \neq -1$$

$$\int e^{ax}\,dx = \frac{1}{a}e^{ax}$$

$$\int \frac{dx}{x+a} = \ln|x+a|$$

$$\int \cos(ax)\,dx = \frac{1}{a}\sin(ax)$$

$$\int \sin(ax)\,dx = -\frac{1}{a}\cos(ax)$$

VECTOR PRODUCTS

$\vec{A}\bullet\vec{B} = AB\cos\theta$

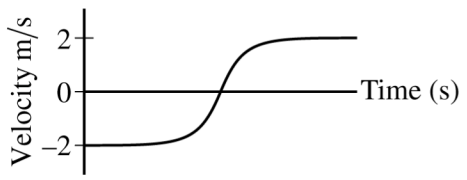
$\left|\vec{A}\times\vec{B}\right| = AB\sin\theta$

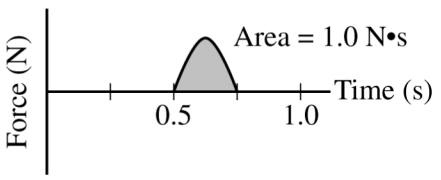
PHYSICS C: MECHANICS
SECTION II
Time—45 minutes
3 Questions

Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.



1. A student sets up an experiment with a cart on a level horizontal track. The cart is attached with an elastic cord to a force sensor that is fixed in place on the left end of the track. A motion sensor is at the right end of the track, as shown in the figure above. The cart is given an initial speed of $v_0 = 2.0$ m/s and moves with this constant speed until the elastic cord exerts a force on the cart. The motion of the cart is measured with the motion detector, and the force the elastic cord exerts on the cart is measured with the force sensor. Both sensors are set up so that the positive direction is to the left. The data recorded by both sensors are shown in the graphs of velocity as a function of time and force as a function of time below.





(a) Calculate the mass m of the cart.

For time period from 0.50 s to 0.75 s, the force F the elastic cord exerts on the cart is given as a function of time t by the equation $F = A\sin(\omega t)$, where $A = 6.3$ N and $\omega = 12.6$ rad/s.

(b) Using the given equation, show that the area under the graph above is 1.0 N•s .

Question 1 continues on the next page.

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(c) The experiment is repeated using a different cord that exerts a larger average force on the cart. The cart starts and ends with the same speeds as those in the original experiment. Will the area for the graph of force as a function of time for the new cord be greater than, less than, or equal to the area for that of the original cord?

____ Greater than ____ Less than ____ Equal to

Justify your answer.

The elastic cord from the original experiment can be modeled as an ideal spring with force constant k.

(d) Derive an expression for the maximum change in length x_{MAX} for the cord. Express your answer in terms of m, k, v_0, and physical constants, as appropriate.

The student performs several trials of the experiment. For the first trial, the cart is empty. In each succeeding trial, a block is added to the cart. In all trials, the cart has an initial speed of $2.0\ \text{m/s}$ to the right, the cart rebounds to the left with a speed of $2.0\ \text{m/s}$, and the maximum change in length of the elastic cord is measured. The total mass M of the cart and the maximum change in length of the cord in each trial are recorded in the table below.

Total Mass of Cart M (kg)	x_{MAX} (m)		
0.25	0.142		
0.75	0.253		
1.25	0.349		
1.75	0.431		
2.25	0.465		

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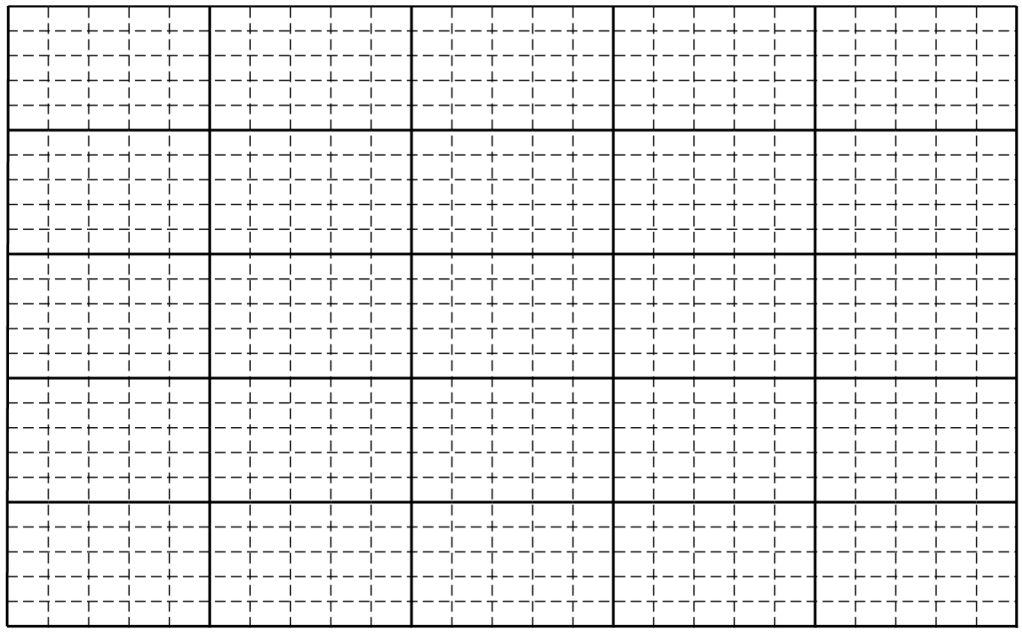
(e) Indicate below which quantities should be graphed to yield a straight line with a slope that could be used to calculate a numerical value for the force constant of the elastic cord k.

Vertical axis: _____

Horizontal axis: _____

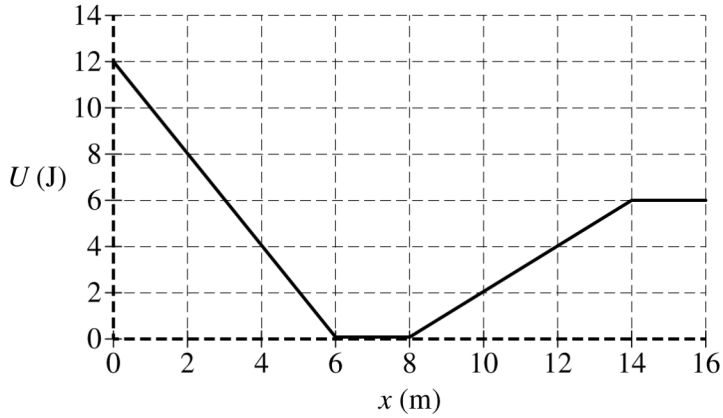
Use the remaining columns in the table on the previous page, as needed, to record any quantities that you indicated that are not given.

(f) Plot the data points for the quantities indicated in part (e) on the graph below. Clearly scale and label all axes, including units as appropriate. Draw a straight line that best represents the data.



(g) Use the best-fit line to calculate the force constant k of the elastic cord.

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2. The variable x represents the position of particle A in a two-particle system. Particle B remains at rest. The above graph shows the potential energy $U(x)$ of the system as a function of position x of particle A, which has a mass of 0.40 kg. Particle A is released from rest at the position x = 2.0 m. Assume positive to be toward the right.

(a) Calculate the speed of particle A when it reaches position x = 14.0 m.

(b)

i. Calculate the magnitude of the acceleration of particle A when it reaches position x= 3.0 m.

ii. What is the direction of the acceleration of particle A when it reaches position x= 3.0 m?

____ Left ____ Right

(c) Determine the magnitude of the acceleration of particle A when it reaches position x = 7.0 m.

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(d) Particle A is again released from rest at the position $x = 2.0$ m.

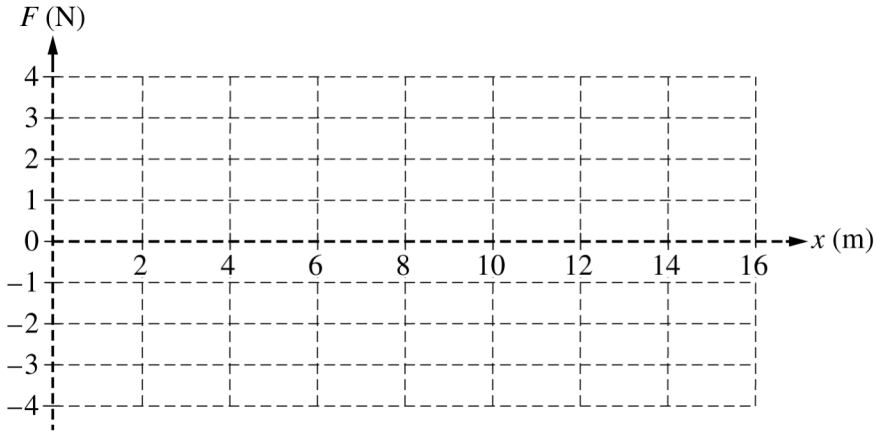
i. Calculate the elapsed time for particle A to travel from position $x = 2.0$ m to position $x = 6.0$ m.

ii. Calculate the elapsed time for particle A to travel from position $x = 6.0$ m to position $x = 8.0$ m.

iii. Calculate the elapsed time for particle A to travel from position $x = 8.0$ m to position $x = 14$ m.

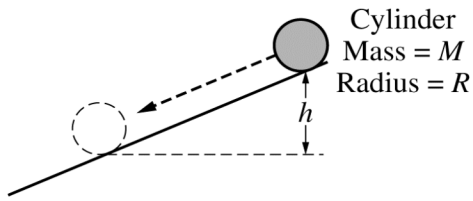
(e) Particle A is now placed at position $x = 7.0$ m. In order for particle A to reach the position $x = 16.0$ m and to be moving at a speed of $1.0\ \text{m/s}$, what initial speed should particle A be given at its new initial position of $x = 7.0$ m?

(f) On the grid below, carefully draw a graph of the force F acting on particle A as a function of x for the range $0 < x < 16$ m.



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GO ON TO THE NEXT PAGE.



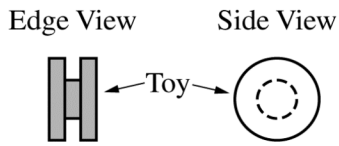
3. A cylinder of mass M and radius R is released from rest at the top of an inclined plane, as shown above. The cylinder rolls without slipping down the incline. The rotational inertia of the cylinder is $MR^2/2$.

   (a) Derive an expression for the angular momentum of the cylinder about its center of mass when it has rolled a vertical distance h. Express your answer in terms of M, R, h, and physical constants, as appropriate.

   (b) Is the angular momentum of the cylinder conserved as the cylinder rolls down the vertical distance h ?

   ____ Yes ____ No

   Justify your answer.

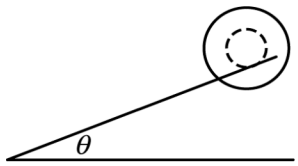


A child's toy is composed of 3 narrow cylinders attached around a common axis through their centers, as shown above. The central cylinder has a mass M and radius R. Each of the two outer cylinders has a mass M and radius $2R$.

   (c) Derive an expression for the rotational inertia of the toy around its center. Express your answer in terms of M, R, and physical constants, as appropriate.

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GO ON TO THE NEXT PAGE.



The toy is placed on a narrow track that is inclined at an angle of θ above the horizontal. Only the central cylinder is in contact with the track, as shown above. The toy rolls without slipping down the track.

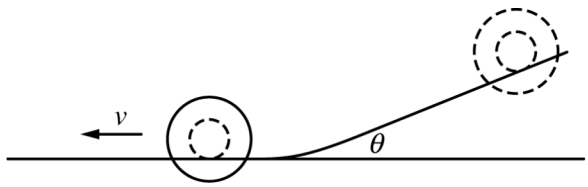
(d)

i. On the dot below, which represents the toy, draw and label the forces (not components) that act on the toy. The dashed line is parallel to the narrow track. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.



ii. Derive an expression for the linear acceleration of the toy as it rolls down the track. Express your answer in terms of M, R, θ, and physical constants, as appropriate.

iii. Determine the force of friction exerted on the toy as it rolls down the track. Express your answer in terms of M, R, θ, and physical constants, as appropriate.



(e) The toy reaches the bottom of the incline and rolls at constant speed v along a horizontal section of the track, as shown above. Derive an expression for the total kinetic energy of the toy while it is rolling. Express your answer in terms of M, R, v, and physical constants, as appropriate.

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THIS PAGE MAY BE USED FOR SCRATCH WORK.

STOP

END OF EXAM

THE FOLLOWING INSTRUCTIONS APPLY TO THE COVERS OF THE SECTION II BOOKLET.

- **MAKE SURE YOU HAVE COMPLETED THE IDENTIFICATION INFORMATION AS REQUESTED ON THE FRONT AND BACK COVERS OF THE SECTION II BOOKLET.**
- **CHECK TO SEE THAT YOUR AP NUMBER LABEL APPEARS IN THE BOX ON THE COVER.**
- **MAKE SURE YOU HAVE USED THE SAME SET OF AP NUMBER LABELS ON ALL AP EXAMS YOU HAVE TAKEN THIS YEAR.**

Multiple-Choice Answer Key

The following contains the answers to
the multiple-choice questions in this exam.

Answer Key for AP Physics C: Mechanics

Practice Exam, Section I

Question 1: B

Question 2: E

Question 3: D

Question 4: C

Question 5: A

Question 6: E

Question 7: B

Question 8: A

Question 9: D

Question 10: D

Question 11: C

Question 12: E

Question 13: E

Question 14: A

Question 15: D

Question 16: A

Question 17: E

Question 18: D

Question 19: D

Question 20: C

Question 21: E

Question 22: E

Question 23: E

Question 24: A

Question 25: E

Question 26: E

Question 27: D

Question 28: C

Question 29: C

Question 30: C

Question 31: C

Question 32: A

Question 33: D

Question 34: C

Question 35: A

Free-Response Scoring Guidelines

The following contains the scoring guidelines
for the free-response questions in this exam.

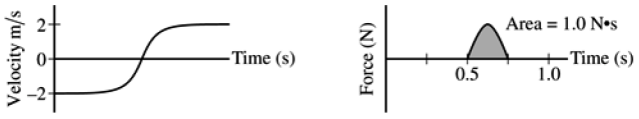
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Question 1

15 points total **Distribution of points**



A student sets up an experiment with a cart on a level horizontal track. The cart is attached with an elastic cord to a force sensor that is fixed in place on the left end of the track. A motion sensor is at the right end of the track, as shown in the figure above. The cart is given an initial speed of $v_0 = 2.0$ m/s and moves with this constant speed until the elastic cord exerts a force on the cart. The motion of the cart is measured with the motion detector, and the force the elastic cord exerts on the cart is measured with the force sensor. Both sensors are set up so that the positive direction is to the left. The data recorded by both sensors are shown in the graphs of velocity as a function of time and force as a function of time below.



(a) 2 points

Calculate the mass m of the cart.

For correctly using the area under the graph to calculate the mass of the cart		1 point
$J = Area = \Delta p = m(v_2 - v_1)$		
For a correct answer with units		1 point
$m = \dfrac{Area}{(v_2 - v_1)} = \dfrac{(1.0\ \text{N•s})}{(2.0\ \text{m/s} - (-2.0\ \text{m/s}))}$		
$m = 0.25$ kg		

For time period from 0.50 s to 0.75 s, the force F the elastic cord exerts on the cart is given as a function of time t by the equation $F = A\sin(\omega t)$, where $A = 6.3$ N and $\omega = 12.6$ rad/s.

(b) 2 points

Using the given equation, show that the area under the graph above is 1.0 N•s .

For relating the time integral of given equation to the area under the curve		1 point
For applying the correct limits of integration		1 point
$J = Area = \int_{0.50}^{0.75} A\sin(\omega t)dt$		
$J = -\dfrac{A}{\omega}[\cos(\omega t)]_{0.50}^{0.75} = -\dfrac{(6.3\ \text{N})}{(12.6\ \text{rad/s})}[\cos(12.6t)]_{0.50}^{0.75}$		
$J = -(0.50)(\cos[(12.6)(0.75)] - \cos[(12.6)(0.50)])$		
$J = 1.0$ N•s		

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Question 1 (continued)

Distribution of points

(c) 2 points

The experiment is repeated using a different cord that exerts a larger average force on the cart. The cart starts and ends with the same speeds as those in the original experiment. Will the area for the graph of force as a function of time for the new cord be greater than, less than, or equal to the area for that of the original cord?

____ Greater than ____ Less than ____ Equal to

Justify your answer.

For selecting "Equal to" with an attempt at a relevant justification		1 point
For a correct justification		1 point
Example: Since the cart starts and ends at the same velocity, the impulse on the cart will be the same so the area under the graph will be the same. Note: If the wrong selection is made, the justification is ignored.		

The elastic cord from the original experiment can be modeled as an ideal spring with force constant k.

(d) 2 points

Derive an expression for the maximum change in length x_{MAX} for the cord. Express your answer in terms of m, k, v_0, and physical constants, as appropriate.

For correctly using conservation of energy		1 point
$U_{MAX} = K_{MAX}$		
$\frac{1}{2}kx_{MAX}^2 = \frac{1}{2}mv_0^2$		
For a correct answer		1 point
$x_{MAX} = v_0\sqrt{\frac{m}{k}}$		

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Question 1 (continued)

Distribution of points

The student performs several trials of the experiment. For the first trial, the cart is empty. In each succeeding trial, a block is added to the cart. In all trials, the cart has an initial speed of $2.0\ \text{m/s}$ to the right, the cart rebounds to the left with a speed of $2.0\ \text{m/s}$, and the maximum change in length of the elastic cord is measured. The total mass M of the cart and the maximum change in length of the cord in each trial are recorded in the table below.

Total Mass of Cart M (kg)	x_{MAX} (m)		
0.25	0.142		
0.75	0.253		
1.25	0.349		
1.75	0.431		
2.25	0.465		

(e) 1 point

Indicate below which quantities should be graphed to yield a straight line with a slope that could be used to calculate a numerical value for the force constant of the elastic cord k.

Vertical axis: _____

Horizontal axis: _____

Use the remaining columns in the table on the previous page, as needed, to record any quantities that you indicated that are not given.

For correctly indicating two variables that will yield a straight line that could be used to determine a value for k		1 point
Example: Vertical Axis: x_{MAX} *Horizontal Axis:* $\sqrt{m}$		
Note: Student earns full credit if axes are reversed or if they use another acceptable combination		

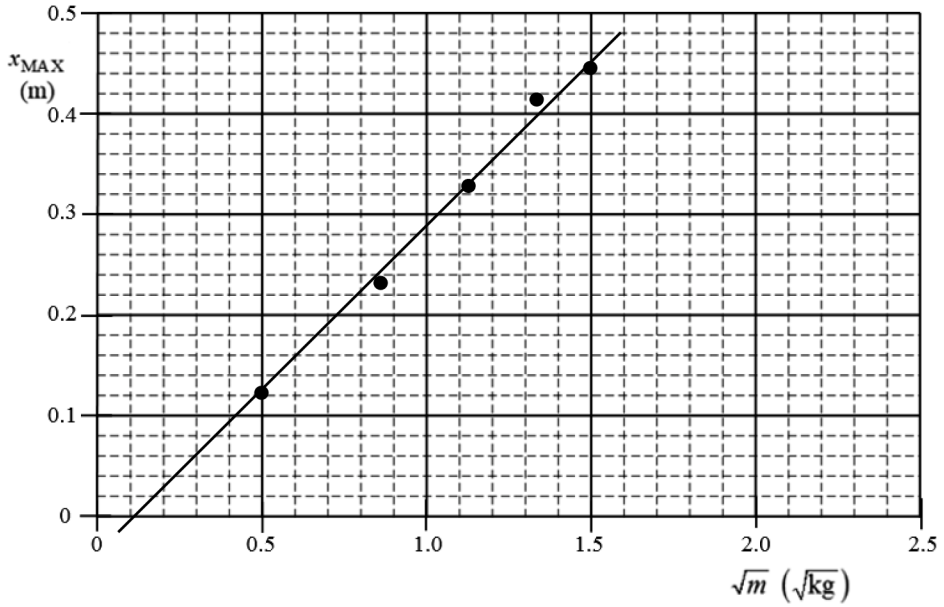
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Question 1 (continued)

Distribution of points

(f) 4 points

Plot the data points for the quantities indicated in part (e) on the graph below. Clearly scale and label all axes, including units as appropriate. Draw a straight line that best represents the data.



For a correct scale that uses more than half the grid		1 point
For correctly labeling the axis with variables and units consistent with part (e) Note: Student earns full credit if axes are reversed		1 point
For correctly plotting data		1 point
For drawing a straight line consistent with the plotted data		1 point

(g) 2 points

Use the best-fit line to calculate the force constant k of the elastic cord.

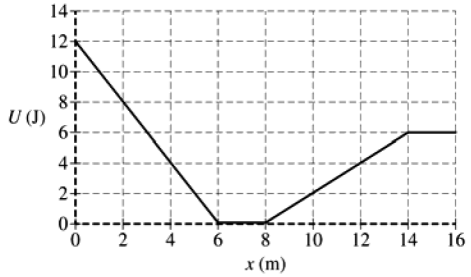
For correctly calculating the slope from the best-fit line and not the data points		1 point
Example: slope $= \frac{\Delta x_{max}}{\Delta\sqrt{m}} = \frac{(0.40 - 0.20)\ \text{m}}{(1.32 - 0.70)\ \sqrt{kg}} = 0.34\ \text{m}/\sqrt{kg}$		
(linear regression slope $= 0.33\ \text{m}/\sqrt{kg}$)		
For correctly relating the slope to the force constant k		1 point
Example: slope $= \frac{v_0}{\sqrt{k}}\ \therefore\ k = \frac{v_0^2}{(\text{slope})^2} = \frac{(2.0\ \text{m/s})^2}{\left(0.34\ \text{m}/\sqrt{kg}\right)^2}$		
$k = 34.6\ \text{N/m}$		
(linear regression $k = 36.7\ \text{N/m}$)		

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Question 2

15 points total **Distribution of points**



The variable x represents the position of particle A in a two-particle system. Particle B remains at rest. The above graph shows the potential energy $U(x)$ of the system as a function of position x of particle A, which has a mass of 0.40 kg. Particle A is released from rest at the position x = 2.0 m. Assume positive to be toward the right.

(a) 2 points

Calculate the speed of particle A when it reaches position x = 14.0 m.

For correctly using conservation of energy		1 point
$U_1 + K_1 = U_2 + K_2$		
$U_1 + 0 = U_2 + \frac{1}{2}mv^2$		
For correctly substituting values from the graph into the equation above		1 point
$(8\text{ J}) = (6\text{ J}) + \left(\frac{1}{2}\right)(0.40\text{ kg})v^2$		
$v = 3.16\text{ m/s}$		

(b)

i) 2 points

Calculate the magnitude of the acceleration of particle A when it reaches position x = 3.0 m.

For correctly relating the slope of the line to the force exerted on the particle		1 point
$F = -\text{slope} = -\frac{(U_2 - U_1)}{(x_2 - x_1)} = -\frac{(12 - 0)\text{J}}{(0 - 6)\text{m}} = 2.0\text{ N}$		
For using Newton's second law to calculate the acceleration of the particle		1 point
$a = \frac{F}{m} = \frac{(2.0\text{ N})}{(0.40\text{ kg})} = 5.0\text{ m/s}^2$		
Note: point is awarded for -5.0 m/s^2		

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Question 2 (continued)

Distribution of points

(b) con't

i) con't

Alternate Solution		*Alternate Points*
Solving for two velocities between 2.0 m and 6.0 m		*1 point*
$v_1 = 0$		
$U_1 + K_1 = U_2 + K_2 \therefore (8\text{ J}) + 0 = 0 + \frac{1}{2}(0.40\text{ kg})v_2^2$		
$v_2 = 6.32\text{ m/s}$		
For using a correct kinematic equation to find acceleration		*1 point*
$v_2^2 = v_1^2 + 2ad \therefore a = \frac{v_2^2}{2d} = \frac{(6.32\text{ m/s})^2}{(2)(4.0\text{ m})} = 5.0\text{ m/s}^2$		
Note: point is awarded for -5.0 m/s^2		

ii) 1 point

What is the direction of the acceleration of particle A when it reaches position $x = 3.0$ m?

____ Left ____ Right

For selecting answer consistent with part (b)(i)		1 point

(c) 1 point

Determine the magnitude of the acceleration of particle A when it reaches position $x = 7.0$ m.

For a correct answer		1 point
$F = -\text{slope} = 0 \therefore a = 0$		
Note: credit is given even if no work is shown		

(d) Particle A is again released from rest at the position $x = 2.0$ m.

i) 2 points

Calculate the elapsed time for particle A to travel from position $x = 2.0$ m to position $x = 6.0$ m.

For using a correct kinematic equation to calculate the time		1 point
$d = v_1 t + \frac{1}{2}at^2 = 0 + \frac{1}{2}at^2$		
For correctly substituting acceleration from part (b)(i) into equation above		1 point
$t = \sqrt{\frac{2d}{a}} = \sqrt{\frac{(2)(6.0-2.0)\text{m}}{(5.0\text{ m/s}^2)}} = 1.26\text{ s}$		

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Question 2 (continued)

Distribution of points

(d) con't

i) con't

Alternate Solution		*Alternate Points*
For correctly using the energy equation to solve for the speed at 6.0 m (or using the value from alternate solution part (b)(i)		*1 point*
$U_1 + K_1 = U_2 + K_2 \therefore (8\text{ J}) + 0 = 0 + \frac{1}{2}(0.40\text{ kg})v_2^2$		
$v_2 = 6.32\text{ m/s}$		
For correctly substituting velocity above and acceleration from part (b)(i) into an appropriate kinematic equation		*1 point*
$v_2 = v_1 + at \therefore t = \frac{v_2 - v_1}{a} = \frac{(6.32\text{ m/s} - 0)}{(5.0\text{ m/s}^2)} = 1.26\text{ s}$		

ii) 2 points

Calculate the elapsed time for particle A to travel from position $x = 6.0$ m to position $x = 8.0$ m.

For using a correct kinematic equation to determine the speed at $x = 6.0$ m or using the velocity at 6.0 m from alternate solutions part (b)(i) or (d)(i)		1 point
$v_2^2 = v_1^2 + 2ad = 0 + 2ad$		
$v_2 = \sqrt{2ad} = \sqrt{(2)(5.0\text{ m/s}^2)(6.0 - 2.0)\text{m}}$		
$v_2 = 6.32\text{ m/s}$		
For using a kinematic equation for zero acceleration to calculate the time		1 point
$d = vt$		
$t = \frac{d}{v} = \frac{(8.0 - 6.0)\text{m}}{(6.32\text{ m/s})}$		
$t = 0.32\text{ s}$		
Alternate Solution		*Alternate Points*
For correctly using the energy equation to solve for the speed at 6.0 m (or using the value from alternate solution part (b)(i)		*1 point*
$U_1 + K_1 = U_2 + K_2 \therefore (8\text{ J}) + 0 = 0 + \frac{1}{2}(0.40\text{ kg})v_2^2$		
$v_2 = 6.32\text{ m/s}$		
For using a kinematic equation with zero acceleration to calculate the time		*1 point*
$d = vt$		
$t = d/v = (8.0 - 6.0)\text{m}/(6.32\text{ m/s})$		
$t = 0.32\text{ s}$		

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Question 2 (continued)

Distribution of points

(d) con't

iii) 1 point

Calculate the elapsed time for particle A to travel from position $x = 8.0$ m to position $x = 14$ m.

For using a correct kinematic equation to calculate the time		1 point
$d = \frac{1}{2}(v_1 + v_2)t$		
$t = \frac{2d}{(v_1 + v_2)} = \frac{(2)(14 - 8.0)\text{m}}{(6.32\ \text{m/s} + 3.16\ \text{m/s})}$		
$t = 1.26$ s		

(e) 1 points

Particle A is now placed at position $x = 7.0$ m. In order for particle A to reach the position $x = 16.0$ m and to be moving at a speed of $1.0\ \text{m/s}$, what initial speed should particle A be given at its new initial position of $x = 7.0$ m?

For correctly using conservation of energy to calculate the speed		1 point
$U_1 + K_1 = U_2 + K_2$		
$0 + \frac{1}{2}m_1v_1^2 = U_2 + \frac{1}{2}m_2v_2^2$		
$\left(\frac{1}{2}\right)(0.40\ \text{kg})v_1^2 = (6\ \text{J}) + \left(\frac{1}{2}\right)(0.40\ \text{kg})(1.0\ \text{m/s})^2$		
$v = 5.57\ \text{m/s}$		

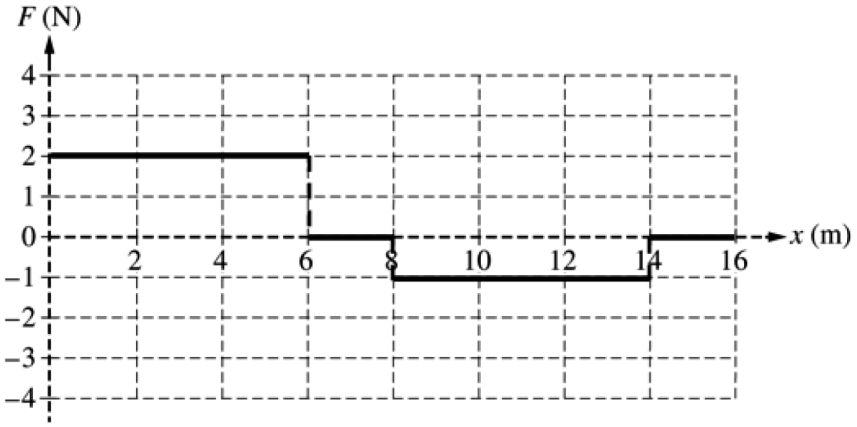
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Question 2 (continued)

Distribution of points

(f) 3 points

On the grid below, carefully draw a graph of the force F acting on particle A as a function of x for the range $0 < x < 16$ m.



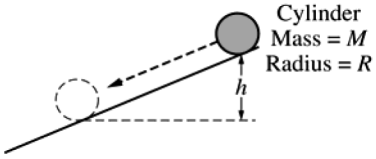
For a horizontal line at $F = 2$ N from $x = 0$ m to $x = 6$ m		1 point
For a horizontal line at $F = 0$ from $x = 6$ m to $x = 8$ m and from $x = 14$ m to $x = 16$ m		1 point
For a horizontal line at $F = -1$ N from $x = 8$ m to $x = 14$ m		1 point
Note: Two points earned if shape and magnitudes are correct but graph is inverted		

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AP® PHYSICS C: MECHANICS
2018 SCORING GUIDELINES

Question 3

15 points total **Distribution of points**



A cylinder of mass M and radius R is released from rest at the top of an inclined plane, as shown above. The cylinder rolls without slipping down the incline. The rotational inertia of the cylinder is $MR^2/2$.

(a) 3 points

Derive an expression for the angular momentum of the cylinder about its center of mass when it has rolled a vertical distance h. Express your answer in terms of M, R, h, and physical constants, as appropriate.

For correctly using conservation of energy		1 point
$U_{g1} + K_1 = U_{g2} + K_2$		
$U_{g1} + 0 = 0 + K_2$		
$mgh = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$		
For correctly substituting into equation above for both linear and rotational kinetic energy		1 point
$Mgh = \frac{1}{2}M(R\omega)^2 + \frac{1}{2}\left(\frac{MR^2}{2}\right)\omega^2$		
$gh = \frac{3}{4}R^2\omega^2$		
$\omega = \sqrt{\frac{4gh}{3R^2}}$		
For correctly substituting into the equation for angular momentum		1 point
$L = I\omega = \left(\frac{MR^2}{2}\right)\left(\sqrt{\frac{4gh}{3R^2}}\right)$		
$L = MR\sqrt{\frac{gh}{3}}$		

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Question 3 (continued)

Distribution of points

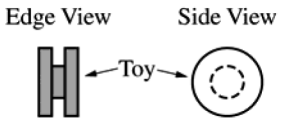
(b) 1 point

Is the angular momentum of the cylinder conserved as the cylinder rolls down the vertical distance h ?

____ Yes ____ No

Justify your answer.

Selecting "No"		
For a correct justification		1 point
Example: The frictional force exerts an external torque on the cylinder therefore the angular momentum of the cylinder is not conserevd.		
Example: The angular velocity is changing with h; therefore, L is changing.		



A child's toy is composed of 3 narrow cylinders attached around a common axis through their centers, as shown above. The central cylinder has a mass M and radius R. Each of the two outer cylinders has a mass M and radius $2R$.

(c) 2 points

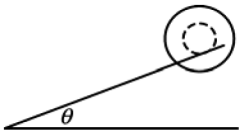
Derive an expression for the rotational inertia of the toy around its center. Express your answer in terms of M, R, and physical constants, as appropriate.

For setting the total rotational inertia for the toy equal to the sum of the rotaional inertias of the three cylinders		1 point
$I_{tot} = 2I_{OUTER} + I_{INNER} = 2\left(\frac{MR^2}{2}\right)_{OUTER} + \left(\frac{MR^2}{2}\right)_{INNER}$		
$I_{tot} = 2\left(\frac{M(2R)^2}{2}\right) + \left(\frac{MR^2}{2}\right) = 4MR^2 + \frac{MR^2}{2}$		
For a correct answer:		1 point
$I_{tot} = \frac{9}{2}MR^2$		

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Question 3 (continued)

Distribution of points

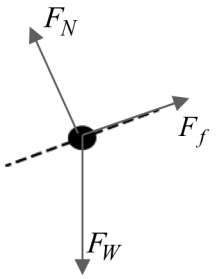


The toy is placed on a narrow track that is inclined at an angle of θ above the horizontal. Only the central cylinder is in contact with the track, as shown above. The toy rolls without slipping down the track.

(d)

i) 3 points

On the dot below, which represents the toy, draw and label the forces (not components) that act on the toy. The dashed line is parallel to the narrow track. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot.



For correctly drawing a vector representing the normal force perpendicular to the dashed line		1 point
For correctly drawing a vector representing the weight of the toy directed straight down		1 point
For correctly drawing a vector representing the frictional force directed up the incline		1 point
Note: A maximum of two points can be earned if there are any extraneous vectors		

ii) 3 points

Derive an expression for the linear acceleration of the toy as it rolls down the track. Express your answer in terms of M, R, θ, and physical constants, as appropriate.

For correctly using Newton's second law in linear form for the toy on the incline		1 point
$F = ma \therefore (3M)g(\sin\theta) - F_f = (3M)a$		
For correctly using Newton's second law in rotational form for the toy on the incline		1 point
$\tau = I\alpha \therefore F_f R = I\alpha \therefore F_f R = \left(\frac{9}{2}MR^2\right)\left(\frac{a}{R}\right) \therefore F_f = \frac{9}{2}Ma$		
For combining the two equation above to calculate the acceleration		1 point
$3Mg(\sin\theta) - \frac{9}{2}Ma = 3Ma \therefore 3g(\sin\theta) = \frac{15}{2}a$		
$a = \frac{2}{5}g(\sin\theta)$		

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Question 3 (continued)

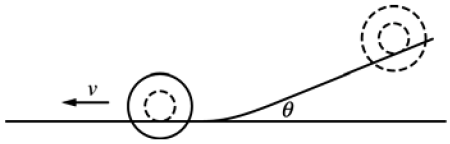
Distribution of points

(d) Con't

iii) 1 point

Determine the force of friction exerted on the toy as it rolls down the track. Express your answer in terms of M, R, θ, and physical constants, as appropriate.

For an answer consistent with part (d)(ii)		1 point
$F_f = \frac{9}{2}M\left(\frac{2}{5}g(\sin\theta)\right) = \frac{9}{5}Mg(\sin\theta)$		



(e) 2 points

The toy reaches the bottom of the incline and rolls at constant speed v along a horizontal section of the track, as shown above. Derive an expression for the total kinetic energy of the toy while it is rolling. Express your answer in terms of M, R, v, and physical constants, as appropriate.

For using both rotational and linear kinetic energy for the total kinetic energy of the toy		1 point
$K = K_L + K_R = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$		
For correctly substituting for both the rotational inertia, the mass, and $\omega = v / R$ into the equation above		1 point
$K = \frac{1}{2}(3M)v^2 + \frac{1}{2}\left(\frac{9}{2}MR^2\right)\omega^2 = \frac{3}{2}Mv^2 + \frac{9}{4}MR^2\left(\frac{v}{R}\right)^2 = \frac{15}{4}Mv^2$		

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Scoring Worksheet

The following provides a scoring worksheet and conversion table used for calculating a composite score of the exam.

2018 AP Physics C: Mechanics Scoring Worksheet

Section I: Multiple Choice

_____	× 1.2857 =	_____
Number Correct (out of 35)		Weighted Section I Score (Do not round)

Section II: Free Response

Question 1	_____ (out of 15)	× 1.0000 =	_____ (Do not round)
Question 2	_____ (out of 15)	× 1.0000 =	_____ (Do not round)
Question 3	_____ (out of 15)	× 1.0000 =	_____ (Do not round)

Sum = _____
Weighted Section II Score (Do not round)

Composite Score

_____	+	_____	=	_____
Weighted Section I Score		Weighted Section II Score		Composite Score (Round to nearest whole number)

AP Score Conversion Chart
Physics C: Mechanics

Composite Score Range	AP Score
55-90	5
42-54	4
33-41	3
24-32	2
0-24	1

Question Descriptors and Performance Data

The following contains tables showing the content assessed,
the correct answer, and how AP students performed on each question.

2018 AP Physics C: Mechanics
Question Descriptors and Performance Data

Multiple-Choice Questions

Question	Topic	Key	% Correct
1	Kinematics	B	93
2	Kinematics	E	82
3	Kinematics	D	22
4	Newton's laws	C	43
5	Newton's laws	A	41
6	Sys of particles & lin mom	E	81
7	Sys of particles & lin mom	B	49
8	Gravity	A	27
9	Gravity	D	58
10	Gravity	D	37
11	Rotation & Circular Motion	C	74
12	Newton's laws	E	65
13	Newton's laws	E	96
14	Newton's laws	A	30
15	Oscillations	D	33
16	Oscillations	A	63
17	Gravity	E	68
18	Gravity	D	64
19	Kinematics	D	90
20	Kinematics	C	97
21	Kinematics	E	16
22	Sys of particles & lin mom	E	82
23	Newton's laws	E	84
24	Sys of particles & lin mom	A	57
25	Work/energy/power	E	42
26	Work/energy/power	E	16
27	Oscillations	D	72
28	Oscillations	C	66
29	Rotation & Circular Motion	C	39
30	Newton's laws	C	59
31	Sys of particles & lin mom	C	47
32	Rotation & Circular Motion	A	60
33	Kinematics	D	89
34	Kinematics	C	89
35	Kinematics	A	78

AP Physics C: Mechanics

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